In the human past, is the perennial consumption of starch a deep or shallow phenomenon?

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Abstract

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Cynthia Larbey

Recent research has argued that digestible carbohydrates, rather than just meat, were necessary to accommodate the metabolic demands of the evolving human brain. This argument is supported by genetic and biological evidence that *Homo sapiens* was especially adapted to a starch diet within the Palaeolithic, making starch consumption a deep phenomenon. Yet there is no deep time archaeological evidence of starch consumption by early humans. A significant body of evidence attests to the increasing starch diet of humans from the Upper Palaeolithic, through the advent of agriculture into the present day where cereals represent 70% of worlds energy intake. Without archaeological evidence of regular early human starch consumption, this appears to be a shallow phenomenon on the timescale of human evolution.

Based on botanical evidence from Klasies River and Blombos Caves, among the earliest human Middle Stone Age (MSA) occupation sites of South Africa, this thesis makes three key arguments: firstly that cooked roots and tubers provided a high quality starch diet for MSA hunter-gatherers from at least 120 thousand years ago in the Cape region; secondly, that pounded, cooked tuber remains and mixed plant food 'recipes' from two hearths (85 kya and 81 kya) at Blombos Cave represent a consistent subsistence strategy through climatic change, one hearth dating to a warm interglacial cycle and the other to a very cold glacial cycle; thirdly, that cooking and processing roots and tubers represent a dietary mainstay

for MSA hunter-gatherers in this region for at least the 55 ky span of the hearths sampled.

The collection and analysis of these data involved an innovative extension of method to overcome difficult preservation conditions. The analysis also benefited from the creation of a regional parenchyma modern reference collection and co-operation with geoarchaeologists to understand the micro-context of each hearth, especially at Klasies River. Combined these method extensions have provided better quality data analysis.

This research offers evidence of the earliest yet known evidence of early human consumption of cooked and processed starchy plants from the MSA of the Cape coast of South Africa. The findings conclude with the hypothesis that perennial starch consumption is a deep phenomenon in the evolution of *Homo sapiens*. The further question must be: How deep is the phenomenon in the ancestors of *Homo sapiens*?

For my husband, Andy Corbett,

whose encouragement and unfailing support
have enriched this adventure that has been my PhD

Table of Contents

Table of Figures

Table of Tables

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Chapter 1

Introduction

1.1 Introduction

This thesis is about the origins of the human starch diet. The following research identifies and exploits new evidence from Blombos Cave and Klasies River, South Africa, providing important findings that are both the first from this region and the earliest known in the world. When synthesised with hypotheses drawn from the most recent human genetics and biology research, and previous approaches to Pleistocene plant subsistence, this thesis extends considerably our understanding of the early modern human starch diet.

This research asks "In the human past, is the perennial consumption of starch a 'shallow' phenomenon; a product of the advent of agriculture during the Holocene or a 'deep' phenomenon; a feature of early *Homo sapiens* in the Pleistocene?

Today, there is much debate about the role that carbohydrate plays in the modern diet. Carbohydrate is the dietary element that provides energy and it is important for a number of biological functions (Hardy *et al*., 2015). Yet the daily recommended amount of carbohydrate is unknown and the Western diet has become defined by high proportions of refined carbohydrates that have contributed to an increase in metabolic diseases such as obesity and Type 2 diabetes. The 'refined' nature of these carbohydrates means that they are essentially 'pre-digested' so that, instead of passing through the digestive system, they immediately break down into free sugars that by-pass the digestion system completely and are metabolised by the liver – turning quickly to fat (Butterworth *et al*., 2011; Englyst and Englyst, 2007). One of the major global health problems is that the Western diet has become 'aspirational' in poor countries (F.A.O. and W.H.O., 1997). With increased affluence, populations worldwide aspire to the

foods of the West and it is adoption of this diet that accelerates the incidence of metabolic disease. The cause is believed to be the association of chronic under-nutrition in the parents associated with adult obesity in their offspring. This has caused a dilemma in developing countries where under-nutrition and obesity are found side-by-side (Portrait *et al*., 2011; Roseboom *et al*., 2006; Schulz, 2010).

The global consumption of carbohydrates is such that worldwide cereal production is dominated by wheat, rice and maize, that together account for 70% of the world's calories (F.A.O., 2014; F.A.O. and W.H.O., 1997). Grain is also used for animal feed and for conversion into cheap starch polymers that coat paper and cardboard and are used in many production processes, including clothes and rubber gloves manufacture (Xie *et al*., 2014).

How did humans reach this point? In the West, fad diets, such as the Paleodiet, insist that high fibre, rather than starchy plant food is better for us, based on the evidence of hunter-gatherer diets (Cordain, 2002). The evidence for the Paleodiet is based on a few highly selective, 30-50 year-old ethnographic accounts of plant collecting by modern hunter-gatherers, for example (Hawkes *et al*., 1982; Lee, 1968). None of these ethnographies were specific studies of plant diets. The origins of the human starch diet are not fully understood.

1.2 The Genetic and Biological Evidence

1) Co-incident with the beginning of the research for this thesis was the publication of new research into human genetic and biological adaptions to a starch diet. It suggests that starch digestion genes (amylase genes) were duplicated in *Homo sapiens*, after the split from the Neanderthal lineage, under selective pressure for a higher carbohydrate diet (Lazaridis *et al*., 2014). This selective sweep dates to around 300 kya, the dawn of *Homo sapiens (*Inchley *et al*., 2016). These findings were supported by Hardy *et al*., (2015) who suggested that the big morphological changes made in the genus, *Homo*, including bigger brains, larger bodies and fat babies, can only have been fuelled by the energy that would come from a diet that included carbohydrates. Biologically, humans require starch for the healthy function of the brain, liver,

kidney medulla, and a healthy reproductive system. These adaptations would imply that a human starch diet is a phenomenon that dates to the emergence of *Homo sapiens*. That being so, where is the archaeological evidence and where might it be found?

1.3 The Archaeological Evidence

The archaeological evidence presents a complex picture of assumptions and gaps in research.

Early genetic research assumed that amylase gene duplications were the result of a higher starch diet, itself a product of increased production of cereals and vegeculture with the advent of agriculture, in other words a 'shallow' phenomenon and a feature of the last 12,000 years. The discovery of amylase duplications in late European hunter-gatherers, however, suggests that this genetic adaptation to a starch diet must have had its origins deeper in the evolution of *Homo sapiens* (Lazaridis *et al*., 2014) and may have been a 'deep' phenomenon, at the dawn of the human species.

Research into plant remains from the late Pleistocene has been limited, but it benefits from exceptional projects, all of which indicate that starch was a regular feature of the early hunter-gatherer diet, with important evidence coming from: Niah Cave, Borneo in Southeast Asia (50 kya) (Barker *et al*., 2007); Kosipe Mission, Papua New Guinea (40-50 kya) (Fairbairn *et al*., 2006; Summerhayes *et al*., 2010); and Madjedbebe, Northern Australia (65 kya) (Clarkson *et al*., 2017). The body of evidence for starchy plant consumption among hunter-gatherers increases in Upper Palaeolithic and Mesolithic and Epi-Palaeolithic periods, producing a significant body of evidence that suggests starchy plant foods were a regular part of the hunter-gatherer diet.

The advent of agriculture occurred at different times across the world but is contained within the last 12,000 years. The archaeological record for the advent of agriculture has prolific evidence of cereal and vegetable domestications (Fuller *et al*., 2014; Zohary *et al*., 2012); methods of discerning production and consumption

(Hillman, 1981; Jones, 1984); worldwide evidence of cereal and vegeculture and global trading of crops (Jones *et al*., 2011). This large body of evidence implies an increase in the human carbohydrate diet. But was this a 'revolution' of diet or simply of production methods in response to an increased population?

The current understanding of the advent of agriculture has been built over decades, by thousands of pieces of research, conducted at sites all over the world. It has been possible to ask big questions about, for example, migration (Chen *et al*., 2015), gendered labour (Molleson, 1994; Molleson, 2000), and the plant food economy (Hillman, 2000; Hillman *et al*., 1989a; Jones *et al*., 2011) because of the scale of this research.

To-date, few big questions have been addressed about the human plant diet in the Palaeolithic. Those questions that have received concerted research focus and broad interpretation across multiple research studies have centred on two major dietary turning points in human evolution: the first after the human/ape split, when early hominins move out of the forest niche and move into an environment of savanna, wetlands and forest, increasing dietary breadth and quality (Hillman and Wollstonecroft, 2016); and the second, at the emergence of the genus *Homo*, when dietary shifts fuel major body morphology changes (Sponheimer and Dufour, 2009). This body of research discusses the increased quality and breadth of the hominin diet, the evidence for which comes largely from nitrogen and carbon stable isotope signatures and occlusal dental wear from hominin fossils (Hardy *et al*., 2015), but also from the analysis of hearth contents (Alperson-Afil and Goren-Inbar, 2010). The evidence specifically for plant diet is not conclusive.

Research into the plant diet of *Homo sapiens* before 60,000 years ago (hereafter kya) is limited to one microfossil study dated to ~120 kya (Henry *et al*., 2014). For a species that may have evolved as early as ~300 kya (Hublin *et al*., 2017), this represents a significant gap in the understanding of the human dietary past. It is, therefore, not surprising that the human carbohydrate diet has hitherto appeared to be a shallow phenomenon: a feature of the advent of agriculture in the Holocene.

1.4 Further Research Considerations

Linked with the acceleration of morphological evolution in the *Homo* species is the ability to control fire and cook. Cooking broadened their diet by: (a) allowing access to plant foods previously indigestible raw; and (b) increasing food bioavailability by pre-digesting meat and plant foods (Carmody and Wrangham, 2009; Carmody *et al*., 2011; Carmody *et al*., 2016; Wrangham *et al*., 1999a; Wrangham, 2009; Wrangham, 2017). If, as is suggested by Carmody *et al*. (2016), adaptations in liver gene expression respond to cooked as opposed to raw food, and that cooking enhances the efficiency of carbohydrate digestion by gelatinizing starch, then evidence for early human starchy plant diet may be found in early modern human hearths used for cooking food. So is there evidence of perennial consumption of starchy plant foods that might support a direct correlation between starchy plant intake and a duplication in the starch digestion genes; or is there occasional evidence of consumption, that might support the hypothesis that cooked food, rather than quantity, was responsible for the gene duplication?

The presence/absence of charred starchy plant remains from intact hearths in Middle Palaeolithic/MSA contexts would represent evidence of early human consumption of starchy plants. Evidence regularly recovered from hearths that span occupation sequences across more than one location would imply perennial consumption of starch carbohydrates. Occasional evidence might suggest that starchy plant foods were a fallback food, as suggested by Laden and Wrangham (2005) and cooking them triggered the genetic response.

Other than cooking, the research invites a further question: is there evidence of other forms of processing? Apes provide a baseline of behaviour for comparison (Jones, 2009a). Chimpanzees have been known to forage for food in post-wild fire landscapes (Pruetz and Herzog, 2017); have been recorded as consuming 163 different plant parts, with one third used for medicines (Krief *et al*., 2005); and savanna chimps have been recorded using tools to dig up corms and tubers (McGrew, 2007). It is suggested that humans have a greater ecological intelligence, the knowledge of plants, their location, their fruiting habits and their properties. Jones (2009) identifies plant groups such as monocots and legumes as

having readily identifiable foliage, no matter the species, all over the world, thereby giving a means of navigating large numbers of starchy food bearing plants in new ecosystems. This ecological intelligence evolved sufficiently that humans were able to adapt to different environments and use food processing to modify different ecological niches (Hillman and Wollstonecroft, 2016; Jones, 2009a; Wollstonecroft, 2011). Indications of processing would be plant remains from Class A contexts that showed signs of pounding, grinding, soaking, fermenting, dehydrating and wet/dry thermal cooking (Hillman and Wollstonecroft, 2016).

Humans have inhabited almost every biome on the planet, testament to their plasticity and dietary flexibility. This has been seen clearly in the development of new hunting strategies and technologies as people moved into new areas or where climate change presented different prey animals. But lack of research in early human time depths means that no such pattern has been seen in plant foods, even if they are fallback foods.

The importance of this research lies in that modern human populations' dispositions to obesity and Type II diabetes today can be found, in part, in their genetic heritage (Falchi *et al.*, 2014). There is great variation in starch genetic adaptation among populations and understanding the human past carbohydrate diet has implications for understanding how susceptibility to metabolic disease is treated.

1.5 An Introduction to the Chapters

Fundamental to this research was the need to understand the full botanical nature and biochemical composition of starch, and this is discussed in Chapter 2. This chapter provides an important foundation for the hypothesis for this research, which is based on the genetic and biological adaptations humans have made to a starch diet. Chapter 2, therefore, considers the biology of the human starch digestion process and the detail of the genetic duplications of human amylase discussed above and provides the basis from which the critical analysis of some of the methods involving the analysis of starch microfossils introduced in Chapter 3.

Much of the increase in archaeobotanical research over the last decade can be attributed to improved, rather than new, methods. Advances in microscopy technology available to archaeology departments has allowed archaeobotanists to become more detailed in their analyses. Scanning electron and digital microscopes are good examples, where botanical assemblages can be screened first using a normal stereo-microscope but interesting botanical fragments can be explored in more depth using more high-powered microscopes. Chapter 3 reviews the possible methods that were available for this research and the reasons for the choices made.

A global review of existing research offering evidence of starchy plant consumption during the Palaeolithic/Middle Stone Age was undertaken, the results of which are discussed in Chapter 4. This chapter had two aims: firstly, to outline the evidence for the early human starch diet and to cover those changes considered to be key turning points. The chapter starts with primate evidence as a baseline for comparison and then reviews the two key dietary changes among hominins mentioned above. It also covers human control of fire and cooking and evidence for Neanderthal and Denisovan plant diets. Secondly, the research in this chapter aims to find evidence of starchy plant consumption from hunter-gatherer sites, dated as early as possible, from each region of the world. There are vast chronological differences for hunter-gatherer periods between regions, for example the Americas 15-3 kya, compared with Southeast Asia at 50 kya. The research, therefore, has been selected by the author to reflect as far as possible the hunter-gatherer period before any suggestion of cultivation or advent of agriculture. This synthesis of current research offers a very solid foundation for this thesis.

The decision process about where and how to look for evidence of early human starch diet is discussed in Chapter 5. Before fieldwork could begin, decisions about site selection criteria needed to be made, and fieldwork was required to choose appropriate sites. South Africa, at the start of this research, was home to the earliest known early modern human (MSA) occupation sites. More than fifty percent of these are located on the Cape coast of South Africa. This chapter details the fieldwork conducted and the careful analysis made of each site before the ultimate selection of Blombos Cave and Klasies River Cave (Figure 1.1).

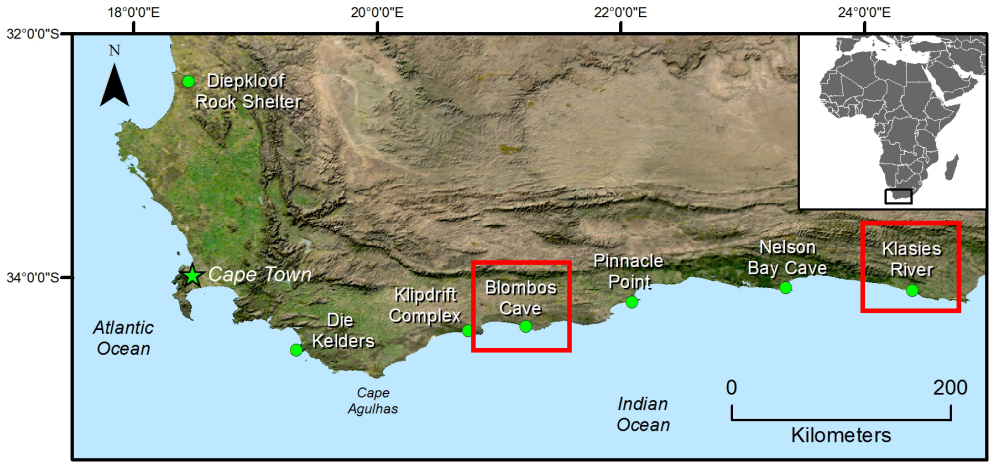


Figure 1.1: Blombos Cave and Klasies River sites, South Africa among other key MSA coastal sites: (Map courtesy of Dr. Magnus Haaland)

The analysis included analysis of preservation conditions, the palaeo-environment and the availability of reference materials. From this, a plan for fieldwork and planned methodology was created. Chapter 5 was created because the preparation detailed here was important to the outcome, but the methodology changed between sites on fieldwork because of the opportunity to work with the micromorphologist at Klasies River. Details of the method used varied from the method planned and this is described in Chapter 6.

This research was the first food-related botanical research conducted at either site. Neither site had any published archaeobotanical research, which meant that there were no previously successful methods that could be replicated. The methodology described in this chapter, therefore, represents the best method available within the archaeobotanical toolkit, with, in a number of cases, tailored extensions of method. The latter may prove useful for future research of this kind in deep time contexts. Suggestions about future methodologies are made at the end of Chapter 6.

Identification of intact hearths was important to provide an unambiguous context in which to identify charred fragments of plant foods. Hubbard and Clapham (1992) identify these contexts as Class A. However, off-hearth samples were also taken and, in the absence of micromorphology analysis at Blombos, some samples were taken from disturbed or mixed hearths; these samples are Class B. The

micromorphology, Fourier-transverse infrared spectroscopy (micro-FTIR) and organic petrology analyses from Klasies River which were made available to the author were invaluable in determining: (a) intact hearths; (b) the ash layers that formed the hearths; and (c) that plant foods were cooked in these hearths along with other foods. This micro-context detail provided better results and more insights, all of which are detailed in Chapter 6.

Details of experimental flotation work are also covered in this chapter. The results from these experiments determined the alternative methodology used at both sites, and this chapter provides useful information on this method for other archaeobotanists.

The sampling strategy and locations were largely determined by the number and location of intact hearths. The decisions made through this identification process are detailed and the step-by-step laboratory process designed to support this sampling method is also described.

Both Blombos Cave and Klasies River sites are located within the Greater Cape Floristic Kingdom: a region renowned both for its general plant diversity but also for its rich diversity of plants with underground storage organs. As a result there are extensive botanical analyses available and, whilst many discuss geophytes, none show underground storage organs - a strategy to prevent visitors digging up plants. With the help of a licensed botanist, the author was able to build a modern parenchyma reference collection, created from plants with underground storage organs gathered from areas around both caves. The method used to collect and create this material is described in this chapter, together with lists of the plant species collected. The collection has provided invaluable comparative material contributing considerable insights to the results of this research and providing a resource for future research.

The results of this research are presented in Chapter 7. Klasies River and Blombos Cave are presented separately but the same format is used in each case. Consideration of each site starts with the outcomes of the micro-context analyses. These results are more detailed in the case of Klasies River where the findings of

botanical remains were supported by confirmation of the identification of intact hearths and the understanding of their contents and stratigraphic relationship. In the case of Blombos, this information was not available and therefore consideration of the site context provides an interesting contrast to the results from Klasies River.

The botanical analyses are then presented, sample by sample, with evidence supported by SEM micrographs. These are accompanied by detailed descriptions of the anatomical characteristics of the samples, an explanation of how these characteristics were identified and consideration of the relevance and/or the implications of that evidence. In these explanations, the 'known' and the 'unknown' are illustrated and described. The reason for this is that future research may find patterns in the unknown, which may prove useful. Despite the small sample size, there is a density analysis for each site in an effort to provide future researchers with a quantitative benchmark.

The findings from the results are presented in Chapter 8, drawing together the outcomes of the analyses of these results. Supported by evidence from this research, these outcomes include observations on hearths, cooking and plant food processing, and these are synthesised to address the research question. The four key themes from these outcomes then contribute to a discussion about the role of starchy plant foods in hominin evolution and the unique knowledge and skills that distinguish humans from other species.

Chapter 2

Human Starch Digestion, Biology and Genetics

2.1 Introduction

Today plant carbohydrates are the most important food element in the modern human diet across the world (FAO and WHO, 1997). Rice, wheat and maize alone account for 65% of that total (FAO, 2014). And yet there are elements of the human carbohydrate diet not fully understood. Carbohydrates can form between 40-80% of the diet, dependent upon regional, cultural or economic considerations. This chapter will start by reviewing what starch is, how starch granules are formed and where it comes from in plants. That humans need starch is demonstrated by the human biological adaptation for digesting and using starch for key biological functions and for energy. This chapter discusses the genetic adaptations to starch as well as the recent research into the role of starch in human evolution. How humans digest starch and where it fits in amongst other elements of carbohydrates are also described. Understanding how starch granules are formed and digested also allows the critical review of the use of starch granules as a method.

Carbohydrate is a large group of organic compounds that includes starch but also sugars and polysaccharides. In the last few years, our understanding specifically of starch and its role in our diet and human evolution has taken a leap forward. In October 2014, a number of genetics papers were published that discussed the hypothesis of a unique human duplication of starch digestion genes (Falchi *et al*., 2014; Lazaridis *et al*., 2014; Prüfer *et al*., 2014a). That this duplication may have originated 300 kya in *Homo sapiens* (Inchley *et al*., 2016) correlates with dating of modern human fossils to 315 ±34 kya from Jebel Irhoud, Morocco, North Africa (Hublin *et al*., 2017). Furthermore, a paper published in 2015 highlighted not only how much human biology relied for health function on a carbohydrate diet, but also how interlinked that was with our evolution and genetic selective pressures

(Hardy *et al*., 2015). These scientific hypotheses highlight a significant gap in archaeological research and evidence on the human starch diet from deep time contexts. The following chapter also reviews these scientific findings and discusses their implications for the research presented here.

2.2 What is starch and where does it come from?

There are still significant gaps in our understanding of the role of starch in the human diet, what is the optimum amount for humans to eat daily and what was its role in human evolution; where did the energy come from that fuelled the significant morphological changes in the human lineage? Research into the role of carbohydrate in our diet is expanding, especially in the fields of how our genes are adapting our starch digestion and the influence of the gut microbiome in human health. This chapter introduces the essential biochemistry, biology and genetics of where starch comes from, how it is constructed, how humans digest starch and, where necessary, how this has evolved.

1. 2.2.1 Where does starch come from?

Starch is the means by which all green plants store energy (Pérez *et al*., 2009; Preiss, 2009). Plants produce starch from glucose made through photosynthesis. Starch is a polysaccharide made up of monosaccharide units. The monosaccharide units link together to form long chain carbohydrates, the simplest being disaccharides when two units join together: *i.e*. sugar from sugar cane and beet comprises glucose + fructose monosaccharides, and milk (maltose) comprises glucose + galactose monosaccharide units. The link between the units is a D-glycosidic bond. This bond is formed between pairs of hydroxl groups, one on each unit (Brown and Brown, 2011; Pérez-Pérez *et al*., 1999).

Polysaccharides are made of many monosaccharide units linked with glycosidic bonds and these chains take two forms: linear and branched.

In the case of starch, the monosaccharide units are all glucose (homopolysaccharide), with two types of starch molecule: amylose, which is

linear; and amylopectin, which is branched (Figure 2.1) (Bertoft, 2017; Brown and Brown, 2011; Buléon *et al*., 1998; Gallant *et al*., 1992; Pérez *et al*., 2009; Tester *et al*., 2004; Xie *et al*., 2014).

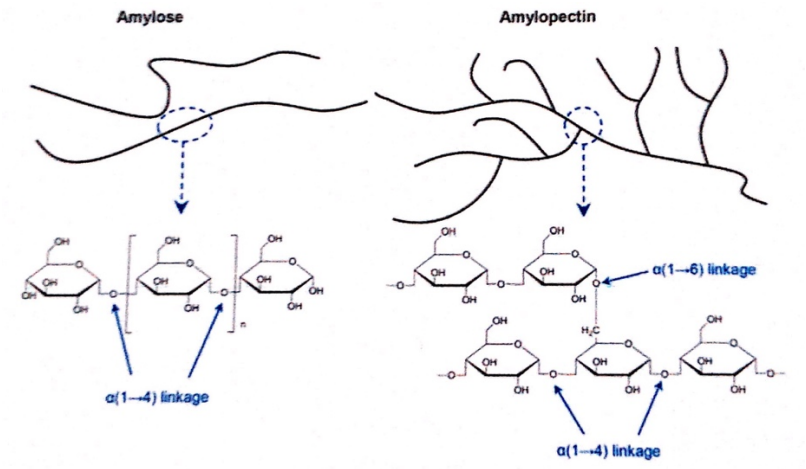


Figure 2.1: The chemical composition of starch (Xie *et al*., 2014)

The difference between these two molecules is that amylose is a linear band of D-glucose unites linked by glycosidic bonds (*alpha* 1 to 4 whereas amylopectin has a branched structure made up of (*alpha* 1 to 4) and (*alpha* 1 to 6) that form the branch points. The branches occur every 24-30 units along the chain. Both molecules have compact coiled structures that enable them to form starch granules (Brown and Brown, 2011).

All plants synthesize both amylose and amylopectin, the latter being the predominant form. Starch is a storage polysaccharide, with the monosaccharide units being used for energy generation by cleaving them from the ends of the molecule chains. In the case of amylose, it only has one end from which monosaccharide units can be cleaved, called the non-reducing end. However, amylopectin, with its branched structure, has many non-reducing ends that can be used concurrently (Brown and Brown, 2011). This balance of amylose and amylopectin has implications for taste and cuisine and possibly for digestibility. High amylose content starches can be difficult to digest and ferment unless processed by soaking and cooking before consumption (Hsu *et al*., 2015).

Plants can vary in the proportions of amylose and amylopectin, some naturally and in some cases have been selected for cultural preference, as in the selection for a mutation of the Wx gene expressed in cereal endosperm, which reduces the amylose content, leaving high amylopectin percentage (Fuller and Castillo, 2016; Fuller and Rowlands, 2009; Hunt *et al*., 2010; Hunt *et al*., 2013). This preference for 'sticky' cereals is prevalent across southern China and Southeast Asia and can include rice, millets and barley (Fuller and Rowlands, 2009). However, high amylopectin content may be significant for processes such as fermentation because of the higher number of non-reducing ends in its branched structure.

In plants, the starch is used in two different ways: The first is as transitory starch, which is found in guard cells that control stomatal pore opening and in the mesophyll or spongy parenchyma layer of leaves, which acts as a short term carbohydrate reserve to sustain the plant's metabolism during darker days and the night (Santelia and Lunn, 2017). The second use for starch is as a reserve to feed new plant growth. The plant uses glucose molecules to store energy as starch granules in parenchyma (Figure 2.2), and is a process that is described below. Parenchyma, the tissue that contains starch granules, can be found in most parts of the plant - stems, leaves and even pollen - but is most abundant in plant storage organs such as roots, tubers and seed endosperm. Through an enzyme initiated process the glucose is deposited in semi-crystalline starch granules (Buléon *et al*., 1998; Gallant, 1996; Preiss, 2009; Smith, 2001; Tester *et al*., 2004; Xie *et al*., 2014).

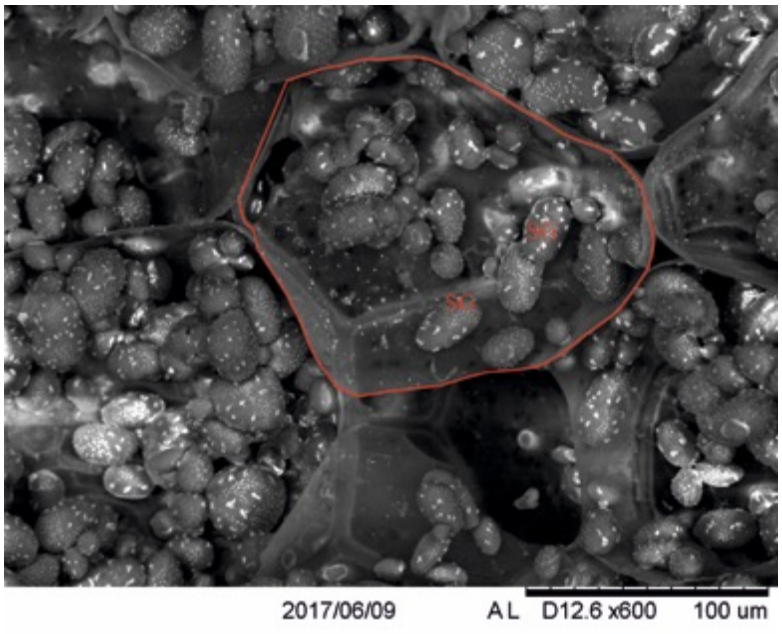


Figure 2.2: SEM micrograph of an *Oxalis* sp. bulb showing parenchyma and starch granules (parenchyma cell outlined in red) filled with starch granules (SG)- from Klasies River modern reference collection (Micrograph: C. Larbey)

Whether stored in leaves, roots or tubers, the starch granules are stored in tissue called parenchyma. Plant parenchyma refers to undifferentiated tissue with thin cell walls, making up the bulk of the soft parts of plants (Hather, 2000) (Figure 2.3).

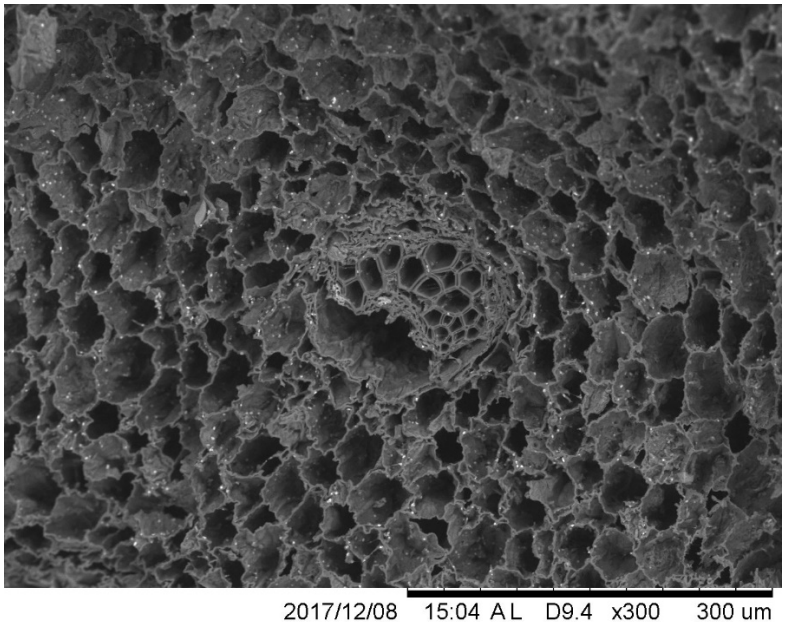


Figure 2.3: SEM of parenchyma, with collenchyma visible in the vascular bundle in the centre of this dried and burned fragment of *Asplenium* sp. from Klasies River, South Africa. Taken from the modern reference collection created for this research (Micrograph: C. Larbey)

Whilst undifferentiated tissue, plant storage organs have morphological characteristics that can often allow the identification of type of storage organ; whether they are monocot or dicot; and occasionally even an identification to plant family. These characteristics include herbivorous defences such as calcium oxalate crystals or secretory cavities that held chemical secondary metabolites that might deter herbivores or attract them (Freeland and Janzen, 1974; Hather, 2000). These morphological characteristics are described in detail in the next chapter. However, they do not allow the identification these plants to species from small fragments of charred parenchyma.

Animals and humans also store starch granules in the cytosol in body tissues but here it is called glycogen. If there are no other forms of immediate energy stores available, glycogen is hydrolyzed, or broken down, into glucose and made available to the rest of the body via the liver (Mathers and Wolever, 2002)

2.2.2 The Starch Granule Structure

The only generalisations that can be made about starch granules is that they store starch for green plants, which can be catalyzed by the plant for future growth and reproduction (Preiss, 2009). How the starch granule is made varies with species, both in the wild plants and with plants that have been bred selectively, as in the case of cereals such as wheat, rice and maize. The number of amylose and amylopectin molecules, the granule structure and the nature and amounts of lipid and protein molecules in each granule vary botanically between species (Jane, 2009; Pérez *et al*., 2009; Smith, 2001; Tester *et al*., 2004; Wilson *et al*., 2010). The sizes of granule can vary in shape and size, ranging from 0.1 μm to at least 200 μm, depending on botanical source (Pérez *et al*., 2009).

When observed under a cross-polarized light in an optical microscope, it is possible to see a 'Maltese cross' extending from an apparent 'hilum', believed to be the starting point of the growth of the starch granule (Figure 2.4). The birefringence shows that the molecules are arranged in a highly ordered radial pattern (Bertoft, 2017; Buléon *et al*., 1998; Gallant *et al*., 1992; Pérez *et al*., 2009; Smith, 2001; Tester *et al*., 2004).

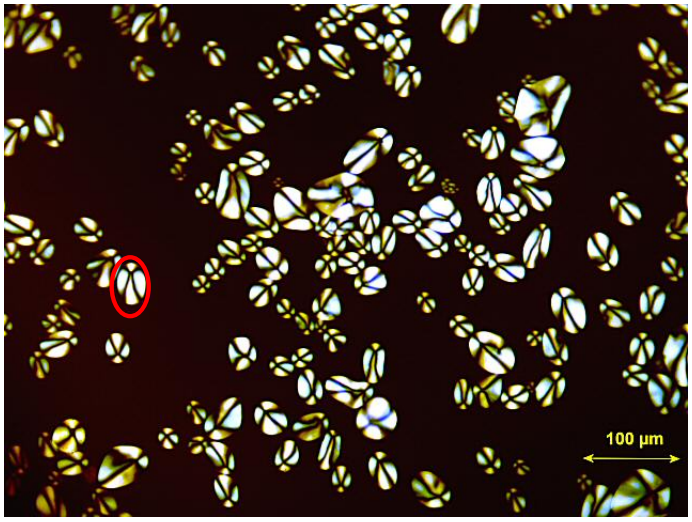


Figure 2.4: Potato starch granules showing 'Maltese cross' (highlighted in red) under polarised light of an optical microscope (Image: Micromagus.net)

The granule consists of two layers, one being a crystalline combination of amylose and amylopectin, the other an amorphous layer that consists of the interlocking branches of amylopectin, and some amylose (Figure 2.5) (Dhital *et al.*, 2017; Smith, 2001).

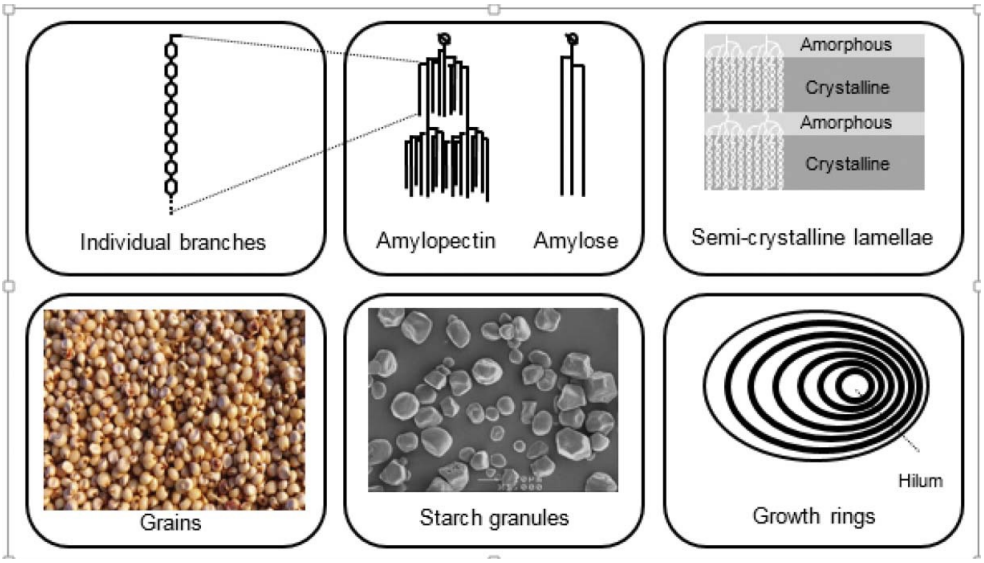


Figure 2.5: The starch granule structure (Image: from (Dhital et al., 2017: 880)

In cross section, the amylopectin and amylose would appear as in Figures 2.6 and 2.7 (Jane, 2009; Torrence, 2006).

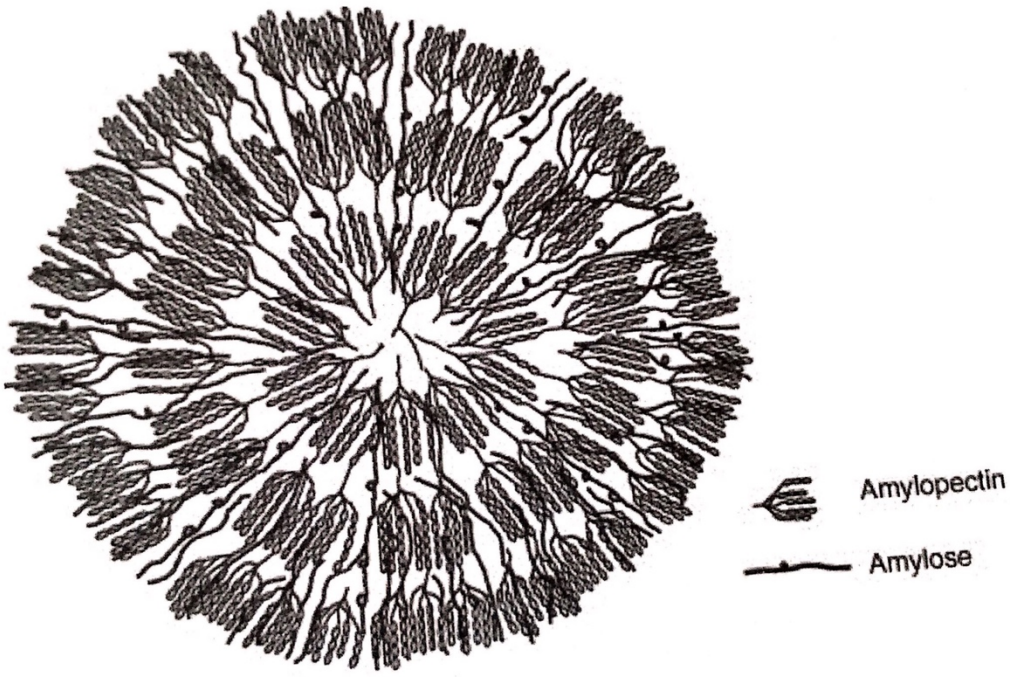


Figure 2.6: Cross-section of the organisation of amylopectin and amylose molecules in a starch granule (Image: adapted from (Jane, 2009: 221). See Figure 2.6 for starch granule in cross-section.

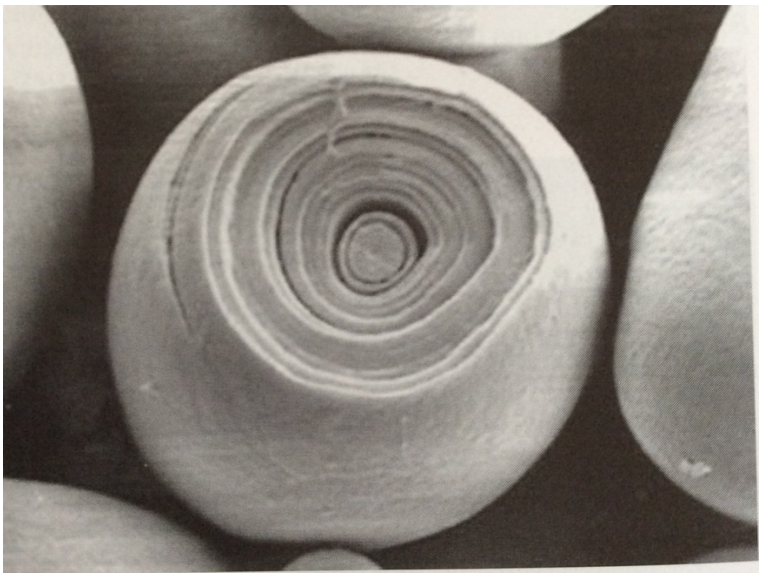


Figure 2.7: SEM micrograph of maize starch granule cross-section (after Torrence, 2006: Plate 15)

Amylopectin is primarily responsible for the crystallinity in starch and can represent between 30-99% of the starch granule and in general is around 70% of the granule (Gallant *et al.*, 1992). Amylose is responsible for some crystallinity but is present in the amorphous layer, which is more susceptible to faster rates of hydrolysis (Buléon *et al.*, 1998; Jane, 2009). The amylose content of a starch grain can vary between 1-83% depending on botanical source and plant breeding

(Bertoft, 2017; Jenkins and Donald, 1995; Xie *et al*., 2014). Starches with little or no amylose are termed 'waxy starches'(Bertoft, 2017; Jane, 2009; Jenkins and Donald, 1995; Pérez *et al*., 2009).

There is little interaction between amylose and amylopectin although this aspect is not well understood (Bertoft, 2017; Dhital *et al*., 2017). In general, the amylopectin size remains constant, but the crystalline element of the granule increases in size. It is suggested that this happens because amylose disrupts the 'packing' of the amylopectin. The amorphous region between the lamellae also increases (Jenkins and Donald, 1995).

In some species as the starch granule matures, the underground roots, seeds, tubers or rhizomes will store lipids as well as starch as an energy source. The amount of lipid varies significantly between species (Turesson *et al*., 2010).

2.2.3 Starch Granules and their Digestion

Starch hydrolysis is the process by which plants and animals break down stored starch into simple sugars to use for energy, growth and reproduction. Genes are specifically encoded to express an enzyme called amylase in plants and animals. Amylase catalyzes the chemical process of hydrolysis. There are two kinds of amylase relevant here: α-amylases, which act at random locations along the starch molecule chain and can break down long-chains, turning carbohydrates into glucose. These α-amylases are the major digestive enzyme in humans and animals, and can also be found in plants, fungi and bacteria. The main form of amylase found in plants, fungi and bacteria, however, is β-amylase which, rather than working randomly as in the α-amylases, works from the non-reducing end of the molecule chain. This means the enzymes start working from the branch ends of any of the molecule chains, rather than working from the middle like the α-amylases. Beta amylases are therefore slower in hydrolyzing starches than the α-amylases (Bertoft, 2017).

Plants express a glycogen branching enzyme gene (GBE1) which cleaves a linear glucose chain and transfers the cleaved portion to a glucose residue within an acceptor chain via an α1,6 linkage to form a branch (Smith, 2001). This process varies with plants that have mutated and varies according to their amylase: amylopectin ratio (Smith, 2001).

2.2.4 Resistant Starch

'Resistant' starch has been defined as starch and starch products that have not been absorbed in the small intestine (Zhang *et al*., 2015). This is often the result of slower enzyme hydrolysis. Amylase can be prevented from hydrolyzing starch in two key ways. Either the enzyme is prevented from binding to the starch by a barrier or there is something inherent in the starch granule itself that inhibits this process. Some species have starch granules with protein and/or lipid matrices on the surface of the granule that prevent the enzyme from binding. The food matrix itself may also prevent access of the amylase to the starch. Soluble fibre, for example, has been shown to form an "enzyme-resistant barrier" around starch granules, by increasing the viscosity of the bolus (Dhital *et al*., 2017):879. Further, if mixed with other foods, the complex mixture of proteins and lipids could also inhibit pancreatic hydrolysis of starch (Bertoft, 2017; Dhital *et al*., 2017; Zhang *et al*., 2015).

The starch granule structure can either inhibit or support amylase hydrolysis. B-type starches, such as potato starch, are more resistant to enzyme hydrolysis because they do not have pores on the surface of the granule in the same way A-type starches have in cereals. The surfaces of starch granules of many cereals (maize, wheat, barley and sorghum) have been shown to have 'pores' in the surface, which are the start of channels that penetrate the granules to the interior (Figure 2.8). The channels are sites of penetration for enzymes but as they contain proteins and phospholipids these could also inhibit hydrolysis (Bertoft, 2017; Dhital *et al*., 2017). The ease with which enzymes are able to penetrate starch granules has implications for processes such as fermentation. Has this morphological feature of starch granules from cereals been exploited for

fermenting for bread and beer making, or have these features been selected for that purpose?

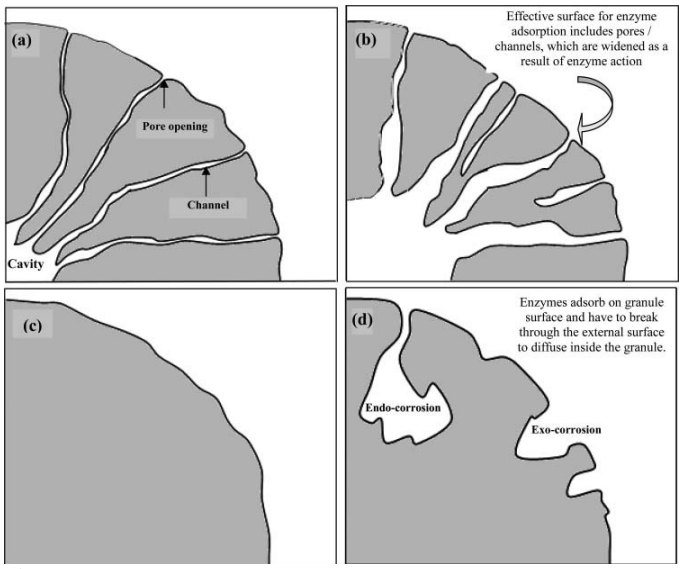


Figure 2.8: Starch granule pores create channels for enzyme access and are responsible for 'inside-out' enzymatic hydrolysis of starch granule. (a) Maize starch; (b) Maize starch hydrolyzed by amylase with enlarged pores, channels and cavity; (c) potato starch lacking pores; (d) potato starch exo- and endo-corroded by amylase (from Dhital *et al*. 2017: 879)

The level of crystallinity in starch granules has been associated with high levels of amylopectin. In the past, this was considered to determine the level of resistance to amylase hydrolysis. However, starch granules that have high amylose show high enzyme resistance. This resistance is now attributed to high molecular density in the arrangement of polymer chains, even in the amorphous non-crystalline chains. In other words, the more tightly packed the molecular chains are in both the crystalline and amorphous lamellae, then the more resistant the starch granule is to amylase enzyme breakdown. Starch granules with a loose molecular arrangement, such as A-type starches, are digested more quickly. Whilst this mechanism has been identified, the chemistry is still not fully understood and is the subject of further food/polymer research (Zhang *et al*., 2015).

2.2.5 The Impact of Processing

Processing can also affect hydrolysis, making starch either more or less available to enzymes. Milling and cooking in water breaks down the complex molecular

structure, such as the long-chain polysaccharides, making them more available for hydrolysis (Nantanga *et al*., 2013; Schnorr *et al*., 2015; Zhang *et al*., 2015). Retrograded starch, such as within rice or pasta, is starch that is cooked in excess water, during which the semi-crystalline starch structure swells and absorbs water, changing to an amorphous (gelatinized) state (Zhang *et al*., 2015). During cooling, the now gelatinized starch transforms from the amorphous state back to a more ordered crystallized state (Zhang *et al*., 2015). Retrograded starch is more generally known in dietary terms as 'resistant starch' because it is slower to be broken down by pancreatic amylase and has varied fermentation time in the small intestine, which is better for health (see Table 2.1) (Englyst and Englyst, 2007).

Starches only fully gelatinize in heated water that is around 2.5 times more water in volume than starch (Bertoft, 2017; Dhital *et al*., 2017; Englyst and Englyst, 2007; Nantanga *et al*., 2013; Schnorr *et al*., 2016a; Schnorr *et al*., 2015; Xie *et al*., 2014). Starches that are roasted or baked do not gelatinize and so their glucose availability, or bioaccessibility, is decreased (Englyst and Englyst, 2007; Schnorr *et al*., 2016a; Schnorr *et al*., 2015). There is also great botanical variation in content and structure of the starch granule which means that some plants have greater carbohydrate bioaccessibility to humans than others (Butterworth *et al*., 2011; Englyst and Englyst, 2007; Pérez *et al*., 2009). To understand better the starch diet of early humans, their choice of tubers, the cooking and processing techniques and how that might affect the bioaccessibility of starch, a study was conducted with modern foragers in Tanzania.

The Hadza are modern foragers in Tanzania, East Africa whose diet is predominantly plant foods (~70%) and which consists largely of wild tubers (Crittenden *et al*., 2013; Marlowe and Berbesque, 2009; Schnorr *et al*., 2015; Vincent, 1985; Woodburn, 1982). The Hadza diet has been researched extensively, with much of the assessment of their diet having been linked to the large size and quantities of tubers for which mainly the women forage (Crittenden *et al*., 2013; Schnorr *et al*., 2015; Vincent, 1985). The tubers eaten by the Hadza are either eaten raw or roasted briefly for 3-9 minutes only, peeled and then chewed over a lengthy period because of the highly fibrous nature of the tubers. The Hadza then spit out wads or quids of fibre into the fire (Schnorr *et al*., 2015). An *in vitro* study

by Schnorr *et al*. highlights the bioaccessibility of glucose of four key species of tubers eaten by the Hadza. The *in vitro* experiment showed that one *Vigna frutescens* is best in cooked form, that *Ipomoea transvaalensis* was probably best eaten raw and *Eminia entennulifa* and *Vatovaea pseudolablab* were not affected by cooking (Schnorr *et al*., 2015: 10). This study concludes that between 30-50% of the available glucose may not be absorbed by the Hadza because of the high proportion of resistant carbohydrate and fibre contained in the tubers. However a previous study of the Hadza gut microbiome suggested that the high diversity of microbes, particularly those in the Bacteroidetes phylum, finished hydrolyzing starches from the highly fibrous plant foods in their diet (Schnorr *et al*., 2014). They may, therefore, absorb more nutrients than the *in vitro* experiment suggested. The Hadza have more duplications of AMY1 than other modern hunter-gatherers. Among the populations tested, the Hadza have between 6-10 copies of the AMY1 gene as opposed to the Mbuti, who live in the rainforest, with 2-6 copies (Perry *et al*., 2007).

Most of the Hadza tubers are high in moisture and this must be a key factor in the dry season. Across arid and semi-arid regions, tubers are used for moisture in the dry season (Bergström and Skarpe, 1981; Schnorr *et al*., 2015; Vincent, 1985).

For archaeologists and anthropologists, these studies are important case studies when assessing and interpreting diet from field evidence. There are a number of botanical, genetic and biological factors that affect starch bioaccessibility before considering processes such as milling/grinding, pounding, leaching, roasting, boiling and chewing. It is the processing and the burned fibrous wads (quids) and peelings that archaeologist most likely find in the archaeological record.

2.3 How Humans Digest Starch

The need for starch as part of the human diet is illustrated by understanding how humans are biologically equipped to digest starch. To understand the importance of the role of starch in our evolution, it is important to review the latest research into one of the largest selective sweeps in the human genome, *i.e*. the duplication of amylase genes responsible for starch digestion, which is also responsible for the

largest area of gene duplication in the human genome (Inchley *et al*., 2016). It is similarly important to review the latest theories on how starch may have provided the energy to fuel the significant evolution in morphology seen in early *Homo* species.

2.3.1 How Humans Digest Starch

In humans and other mammals, two genes are coded for amylase hydrolysis. The gene AMY1 expresses α-amylase in the saliva, which pre-ingests starches into simple sugars. AMY1 is also expressed in mammary glands. AMY2 produces α-amylase in the pancreas, which is secreted into the duodenum in digestive juices, where the process of digestion of starch and other carbohydrate is completed (Butterworth *et al*., 2011; Inchley *et al*., 2016; Mathers and Wolever, 2002).

The human digestive process is complex and involves several enzymes and various hormonal controls that interact with these enzymes (Dhital *et al*., 2017). Not only is there individual variation in human response to starch digestion but how humans digest carbohydrates depends on the chemical nature and molecular structure of the plants themselves (Mathers and Wolever, 2002) .

Table 2.1: Carbohydrate bioavailability classification (from Englyst & Englyst, 2005: 2): RAG = rapidly available glucose; SAG = slowly available glucose; RSCC = resistant short-chain carbohydrates; NSP = non-starch polysaccharides (fibre), i.e. non-digestible. Blue shaded areas = more likely to be metabolized by the liver where they will either used as energy immediately or rapidly deposited as fat.

Main Category	**Chemical Components**	**Nutritional Grouping**	**Main biological function**
Glycaemic carbohydrates	Free sugars	Fructose from free sugars	Largely metabolized by liver. Possible detrimental effect on lipid metabolism
	Maltodextrins	RAG and SAG	RAG and SAG reflect the rate of glucose release from food, which is an important determinant of the glycaemic index. Evidence to suggest that metabolic response associated with slow-release carbohydrates (SAG) are most conducive to optimal health
	Starch		
Non-glycaemic carbohydrates		Resistant starch	Varied rate and extent of fermentation
	NSP	Intrinsic NSP: naturally occurring as cell-wall material in plant foods	Food matrix moderates carbohydrate release. Marker for high-fibre diet, rich in micronutrients - shown to have health benefits
		Added NSP	Varied rate and extent of fermentation
	RSCC	Intrinsic RSCC: natural	Varied rate and extent of fermentation
		Added RSCC	
	Sugar alcohols	Present naturally & added	Absorbed but not metabolized. Fermented

Table 2.1 summarises the different kinds of carbohydrate bioavailability and how humans digest them. Glyaecemic carbohydrates are those carbohydrates that release glucose into the blood. Highly processed foods that contain pre-processed starch, with no fibre so that the enzymes are able to bind instantly with the starch granules, or even where the carbohydrates consumed are in the form of sugars, have a high glycaemic rate and are often metabolized by the liver, excluding the gut completely. Starches from mashed potatoes would be rapidly available glucose (RAG), whereas whole grains and lentils would be slowly available glucose (SAG).

Non-glycaemic carbohydrates are non-starch polysaccharides (NSP) that include cellulose, pectins, glucans, gums, mucilages, inulin and chitin. These NSPs moderate the release of glucose into the blood and ferment in the gut providing a substrate for gut bacteria. The gut microbiome describes a vast number of symbiotic bacteria in the human gastrointestinal system and their collective interactive genomes (Kinross *et al.*, 2011). Recent research has suggested that lack of diversity in gut microbes is linked to a wide range of human diseases.

Conversely, the greater the number and diversity of gut microbes, the more their biochemical activity is related to the maintenance of health (Kinross *et al*., 2011).

2.3.2 Human Biological Need for Starch

There has been debate on whether starch is an essential part of human nutrition. This debate has been fueled by the acceleration of diet-related metabolic diseases, particularly obesity and type two diabetes, where researchers have looked for clues in our past (Hardy *et al*., 2015). These studies focused on a 'low carbohydrate' diet, based on research that synthesised archaeological and published ethnographic research that highlighted the health problems caused by high glycaemic carbohydrates, i.e. highly processed, low fibre, sugary foods (Cordain *et al*., 2000; Cordain *et al*., 2002). In fact, this research addressed the modern western diet that contains a large amount of high glycaemic carbohydrates, quoting hunter-gatherer diets as the optimum and recommended lower not low carbohydrates (Cordain *et al*., 2002).

There is significant evidence that humans are adapted both biologically and genetically to carbohydrates. (Hardy *et al*., 2015).

After cellulose, starch is the second most abundant carbohydrate in nature (Jiang, 2010). Starch is hydrolyzed into a number of sugars, the simplest of which is glucose. This is converted into adrenosine triphosate (ADP), which is a high energy molecule found in every cell in the body, ready to supply energy for what that cell needs to do (Mathers and Wolever, 2002). The non-glycaemic carbohydrate elements such as non-starch polysaccharides and resistant starch, see Table 2.1, are not hydrolyzed by upper gut enzymes but pass into the large intestine, where they are fermented by gut microbiota. Fermentation produces short-chain fatty acids, butyrate, propionate and acetate, which are absorbed from the gut and provide a further 5-10% of adult energy requirements (Hardy *et al*., 2015). A reliable source of carbohydrate is needed to support brain function, including the central nervous system, the kidney medulla, red blood cells and for reproduction (Hardy *et al*., 2015).

The brain is not only responsible for up to 25% of the basal metabolic rate (Hardy *et al*., 2015) but plays a key hierarchical role in its demand on the whole body's energy metabolism (Gobel *et al*., 2010). Called "The selfish brain hypothesis", the brain prioritises its own demand for ADP before that of the rest of the body (Peters *et al*., 2004). This preferential distribution of resources to the brain provides an energy buffer during times of environmental stress (Longman *et al*., 2017).

Starch is also critical in human reproduction. Amylase is present in both the uterus and seminal fluid. In the uterus it protects and feeds the early embryo, and infertile women have been found to have low amylase levels in uterine fluid and it may even be a cause of infertility (Fernández and Wiley, 2017). Amylase in seminal fluid is considered to promote the fertilization ability of spermatozoa (Fernández and Wiley, 2017). Alpha amylase is also higher during the peri-ovulatory period than at any other time of the female ovulating cycle (Fernández and Wiley, 2017). Glucose is the main energy source for fetal growth, particularly in the last trimester. Lack of this glucose endangers the baby's survival (Hardy *et al*., 2015; Herrera, 2000). Amylase is also produced in breast milk. As human infants are born with no pancreatic amylase activity, the amylase passed from mother to infant has been considered to help the infant digest starch at the initiation of weaning and until its own amylase and starch digestion system kicks in (Fernández and Wiley, 2017; Hardy *et al*., 2015).

Low or no carbohydrate diet arguments have pointed to circum-Arctic communities as examples of populations who survive successfully on low carbohydrate diets. Communities with deep DNA lineages in this region, such as the Chukchi, have adapted to the extreme cold and high fat diet through increased basal metabolic rate, low serum lipid levels and increased blood pressure (Cardona *et al*., 2014; Leonard *et al*., 2005). The women successfully meet the energy requirements of pregnancy and breastfeeding through consumption of the stomach chyme of caribou (reindeer), allowing them to access the plant foods grazed by those animals, plus foraged tundra plants and kelp. Glycogen also comes from fresh (or frozen) lean meat. Circum-Arctic populations also have a range of mal-adaptations that allow them cope with both their diet and cold. They have enlarged livers to cope with gluconeogenesis (the formation of glucose from fat or amino

acids from protein) (Hardy *et al*., 2015) and common among these communities, the Canadian and Greenland Inuit and Northeast Siberian communities in particular, is a genetic mal-adaptation that blocks the normal function of the fat catalyzing CPT1A gene. This is a metabolic disorder that confers adaptation to cold and a high fat diet but also presents as hypoketotic hypoglycemia in children, causing high infant mortality in the form of sudden infant death syndrome (Cardona *et al*., 2014; Clemente *et al*., 2014; Collins *et al*., 2010). Amongst the Nunavut, the largest Inuit population in Canada, the sudden infant death rate is seven times higher than the Canadian national average (Collins *et al*., 2010). Whilst circum-Arctic populations successfully raise children, the metabolic mal-adaptations suggest that humans are better adapted to a carbohydrate diet.

2.4 Human Genetic Adaptation to Starch

In 1962, the geneticist James Neel observed that certain populations and communities were susceptible to type two diabetes. Neel's Thrifty Gene Hypothesis suggested that the thrifty gene allowed early human hunter-gatherers, particularly reproductive females, to accumulate fat in times when food was abundant, that would sustain them through times of famine. Neel hypothesized that type two diabetes and obesity were a consequence of this gene in modern times where there is abundant food (Neel, 1962). A recent genetic study looked at all 65 loci connected with the risks of type two diabetes and found no support for positive selection for risky ancestral alleles or population differentiation and, therefore, no support for this hypothesis (Ayub *et al*., 2014). Genetic research into the human starch diet has found adaptations within the human lineage.

The human AMY gene group encode alpha-amylases in the salivary glands and the pancreas for the hydrolysis of carbohydrates into simple sugars. These AMY genes have a variable number of gene copies that are grouped in a tight cluster in a ~200 kb region on the reference assembly on chromosome 1 (Inchley *et al*., 2016). This AMY locus has undergone significant expansion in humans compared to great apes, with the AMY1 gene showing high copy number variation (cnv) within and between populations (Carpenter *et al*., 2015; Iafrate *et al*., 2004; Lazaridis *et al*., 2014; Perry *et al*., 2007; Redon *et al*., 2006; Usher *et al*., 2015). Higher copy

numbers of the salivary amylase gene AMY1 increase expression of salivary amylase, potentially allowing more efficient digestion of starchy foods (Falchi *et al*., 2014; Perry *et al*., 2007).

Initially, this duplication was considered to be the result of a shift from the low starch diet of hunter-gatherers to higher starch diet of Neolithic farmers who domesticated not just grasses that became cereals such as wheat, rice, maize, barley, rye and millet but also wild tubers such as potatoes, sweet potato, cassava (manioc), taro as well as legumes (Fuller *et al*., 2014; Inchley *et al*., 2016; Perry *et al*., 2007). Fruits that contain starch such as banana, mango and pineapple were also domesticated (Fernández and Wiley, 2017).

However, among the nine known genes associated with starch digestion, including amylase genes, only one gene, SLC2A5 (a fructose transporter), underwent selection after the Palaeolithic period, probably following the domestication of specific fruit crops (Pontremoli *et al*., 2015). In general it is considered that the advent of agriculture was not a major selective event for all the starch digestion genes (Pontremoli *et al*., 2015). But current genetic analysis methods make it difficult to detect recent selections. Few advantageous alleles are expected to go to fixation within ten thousand years and few methods are sufficiently powerful to detect the impact of dietary changes associated with the advent of agriculture (Luca *et al*., 2010).

Ancient genetic analysis, however, indicated that Mesolithic European hunter-gatherers from Loschbour, Luxembourg (*c*.10 kya), Stuttgart, Germany (*c*. 8 kya) and Motala, Sweden (*c*. 8 kya) already had AMY1 duplications of 13, 16 and 6 copies respectively (Figure 2.9). These data suggest that AMY1 duplications occurred in the Palaeolithic, before the advent of agriculture (Lazaridis *et al*., 2014).

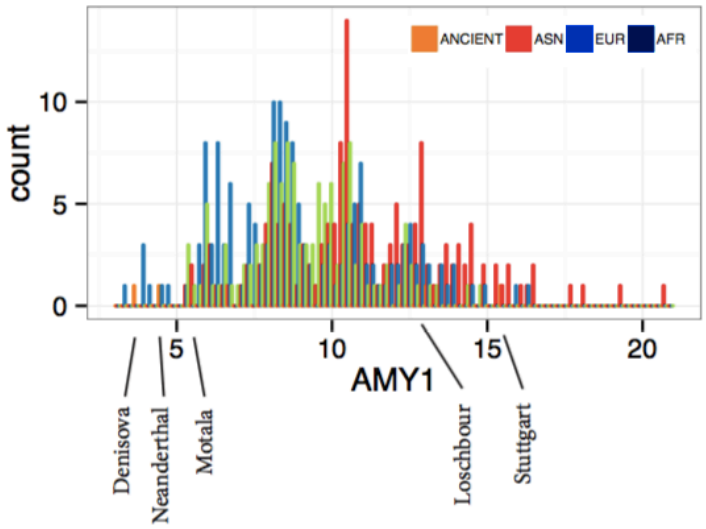


Figure 2.9: AMY1 copy numbers of Mesolithic hunter-gatherers from Motala, Sweden, Loschbour, Luxembourg and Stuttgart, Germany and the copy numbers of Neanderthals and Denisovans (Lazaridis *et al*., 2014): graph used with kind permission of Prof. Peter Sudamant (Prüfer *et al*., 2014a: S.I. 8: 58)

The discovery that the Neanderthal and Denisovan from Altai in Southern Siberia retained only two copies of AMY1 (Prüfer *et al*., 2014b) raised the question about the role of AMY duplication in the evolution of *Homo sapiens* (referred to hereafter simply as humans, as opposed to other archaic *Homo* species such as Neanderthals and Denisovans).

Other starch digestion brush border genes were also already present in the Palaeolithic. Selective sweeps and fixations have been observed in specific populations, *i.e*. SI and SLC2A2 in non-Africans: SI (sucrose isomaltase), which is responsible for starch and sucrose digestion in the small intestine; SLC2A2 (solute carrier family 2 member 2) modulates bidirectional glucose transport in liver, kidneys and intestine (Pontremoli *et al*., 2015).

Whilst a number of great apes eat corms and tubers, genetically there is a mixed picture. Orangutans have raised AMY1 copy numbers of six, whilst chimpanzees and gorillas remain at around two copies but few genetic amylase genetic studies have been conducted on other primates (Lazaridis *et al*., 2014). All great apes are known to consume starchy corms and tubers but they are a routine part of the diet of baboons (Figure 2.10). Non-genetic research has shown that *Papio hamadryas*

and *Therpithecus gelada* baboons have raised salivary alpha-amylase activity above that of humans in a similar test (Mau *et al*., 2010).

Figure 2.10: A Chacma baboon mother preparing to eat a *Watsonia* corm, South Africa (Image: Brett Cole)

And whilst the chimpanzee DNA included in the genetic research has only the two AMY1 copy numbers, these do not include sampling of the savanna chimpanzees of Tanzania, that also dig for roots and tubers (Hernandez-Aguilar *et al*., 2007). There has also been no amylase testing of the swamp gorillas of the Democratic Republic of Congo (DRC), who consume starch rhizomes and tubers on a seasonal basis. (Blake *et al*., 1995). The primate evidence, therefore, is not conclusively different from humans and further genetic research could usefully be conducted in this area.

In non-genetic analyses of amylase activity in carnivores, herbivores and omnivores, the results showed that animals that feed on unripe fruits, seeds, roots and bulbs exhibit higher activity of salivary alpha-amylase than species that consume ripe fruits, insects and vertebrates (Boehlke *et al*., 2015). This multi-method study offers emphasizes that amylase activity is stimulated by higher starch levels, not higher glucose levels.

The duplications of the AMY1 genes in humans have been shown to be functional, as opposed to duplications found in bonobos (*Pan paniscus*), which are non-functional (Falchi *et al*., 2014; Perry *et al*., 2007). Combined, this research has led to a hypothesis that humans adapted to an increased starch diet within the period of the Palaeolithic although when in the Palaeolithic is not known (Inchley *et al*., 2016). Hardy *et al*. have argued that once cooking became widespread ~800 kya, then starch digestion would have been the "rate-limiting step" and that AMY gene cnv was a response to the increased availability of pre-formed glucose offered by cooking (Hardy *et al*., 2015:253). Carmody *et al*. argued for this adaptation being a feature of the last 275 kya (Carmody *et al*., 2016). Assessment of AMY copy numbers in a global sample of high coverage genomes supported a model for an early selective sweep. These findings suggest that this duplication occurs in the human lineage after the split from Neanderthals, leading to a fixation of six copies AMY1 in place of the ancestral diploid two copies (Figure 2.11).

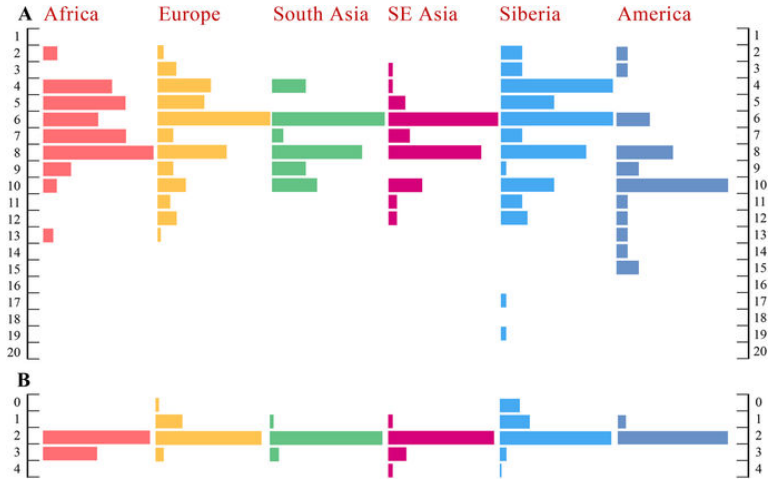


Figure 2.11: Distributions of AMY1 (A) and AMY2a (B) copy numbers across major continental groups. Image taken from Inchley *et al*. (2016: 6)

Inchley *et al*.'s research suggests that an initial duplication occurred 300 kya before humans started to diversify (Inchley *et al*., 2016). It further seems likely that human populations dispersing out of Africa were already carrying a new ancestral copy number of between six to eight copies of AMY1 (Inchley *et al*., 2016). Populations outside Africa with fewer copies are due to secondary losses rather than retention of the original ancestral two copies (Inchley *et al*., 2016).

There also appears to be a significant correlation between geographical latitude and AMY1 copy numbers. Low latitudes appear to have higher AMY1 copy numbers than high latitudes. Deletions of both AMY1 and AMY2a are common in high latitude Siberian populations, whereas duplications were more common in lower latitudes. And duplications of the pancreatic amylase genes AMY2a and AMY2b are specific to African and West Eurasian populations (Inchley *et al.*, 2016).

The conclusions of many of these papers are that the selective pressure and ultimate fixation of these AMY1 and AMY2 duplications were caused by an increase in starch diet. This starch diet increased through greater availability made possible by the methods of processing such as cooking and grinding that made more starchy foods available.

Food processing has typically been seen as an adaptation to evolutionary changes, such as increase in brain size and cognition, rather than an initiator of these changes (Wollstonecroft, 2011). The ability to process and cook foods provided early modern humans with not only significantly greater dietary breadth but greater flexibility (Hillman and Wollstonecroft, 2016). Wollstonecroft (2011) argues that from an NCT perspective, processing and cooking foods gave humans the ability to modify evolutionary selection pressures "*…through innovation, learning, material culture and the cultural transmission of knowledge (all important components of human food-processing traditions) ..*" (Wollstonecroft, 2011: 144). It is further argued that this cultural transmission can accelerate the rate at which a favoured gene spreads. This theory may have some relevance in relation to the amylase starch gene adaptations in humans; the greater the breadth of year-round starchy plant foods, there is greater flexibility to move into new environments and sustain a high quality diet, which would improve population health and thereby accelerate the selection process.

There are a small number of counter arguments that AMY1 plays a limited role in starch digestion. The only function of the AMY1 gene is to express alpha-amylase to break down starch into simple sugars ready for digestion, and duplications and

their role in evolution have been over-interpreted (Fernández and Wiley, 2017). There are many other enzymes involved in starch digestion (Fernández and Wiley, 2017). Further amylase expression is influenced by stress, physical exercise and pH levels as salivary amylase secretion is regulated by the sympathetic nervous system (Fernández and Wiley, 2017; Mandel *et al*., 2010; Santos *et al*., 2012).

Fernández and Wiley have consequently argued that it is too early to interpret AMY1 duplication as a dietary adaptation and there may be other explanations for AMY1 duplication (Fernández and Wiley, 2017). They have also criticized the use of some of the earlier methods, such as qPCR (polymerase chain reaction, used to amplify copies of a segment of DNA) used in these genetics studies, citing their lack of accuracy. It is generally accepted that salivary amylase plays an important role in starch digestion in the pancreas, with 55-60% of serum amylase (amylase levels in blood or urine) coming from salivary amylase (Fried *et al*., 1987).

As ever, methods improve constantly, and our understanding of the genetics of human amylase, whilst full of gaps, has also improved, yet the AMY group remains a central feature of research into human starch diet and findings remain consistent, supporting interpretations of dietary adaptation. Recent research findings link higher copies of AMY1 and AMY2 amylase genes with protection against obesity (Bonnefond *et al*., 2017; Carpenter *et al*., 2015; Falchi *et al*., 2014; Mejia-Benitez *et al*., 2015).

The variation in AMY duplications appears to be associated with latitudes that suggest a link to environmental food availability. Other human genetic dietary adaptations support this idea. The mutation of the fat catalyzing gene CPT1A among circum-Arctic populations discussed above is a clear adaptation to environment (Clemente *et al*., 2014). The LCT (lactose) gene that is responsible for digesting milk but which usually becomes inactive after weaning in most humans (and mammals), becomes persistent in populations whose subsistence is highly dependent upon dairy products both in Europe and Africa (Swallow, 2003; Tishkoff *et al*., 2007).

The duplication of the AMY genes has been associated with the advent of cooking and the increased availability of carbohydrates. Cooking will detoxify and improve the digestibility and palatability of starchy plants and thereby increase the range of plants consumed (Hardy *et al*., 2015). It is possible that increased quantity produced the duplication. However, the advent of cooking happened around 800 kya yet this duplication appears only in the human species 300 kya. Neanderthals and Denisovans do not appear to have this duplication despite evidence of cooking in very similar ways to humans (Henry *et al*., 2014; Madella *et al*., 2002), although the sample of one of each fossil may not be decisive.

There are other hypotheses about AMY1 duplication in particular to consider. As described above, AMY1 is expressed in mammary glands for breastmilk, which continues until weaning ends. (Butterworth *et al*., 2011; Fernández and Wiley, 2017; Swallow, 2003). Infants are born without any amylase capacity and their own amylase initiates only at weaning (Butterworth *et al*., 2011). AMY1 is also expressed in the uterus and seminal fluid and has a role in fertility and reproduction, together with an important role in infant nutrition and survival (Fernández and Wiley, 2017; Hardy *et al*., 2015). From a human evolutionary and survival perspective, the role of AMY1 in successful reproduction would have a strong selective pressure.

There are other aspects of starch consumption that have not yet been researched that could also have an impact on amylase production. Pre-mastication for weaning and chewing for nutrition/moisture has both archaeological, anthropological and modern evidence. Agave is a cactus-style monocot plant that grows in the arid regions of the American southwest and Mexico. Evidence dated to 1400-1200 years ago from Durango, Mexico shows that this plant was consumed regularly. Agave contains soluble carbohydrate, but it is highly fibrous and the evidence comes from dental records and quids, small bundles of fibrous remains of the plant, that were expectorated after long chewing (Hammerl *et al*., 2015). In arid regions plants would have been a source of moisture and in Africa certain species of plants with large tubers are excavated purely for their moisture content (Bergström and Skarpe, 1981). The association of starch consumption with hydration is strong and high amylose maize starch has for over forty years been

part of oral rehydration therapy because of its effectiveness in stopping diarrhoea, the major cause of dehydration (Binder *et al*., 2014). The Hadza only briefly roast their tubers to loosen the outer bark. Pre-mastication used for weaning appears in most hunter-gatherer societies that include the Kung! San in southern Africa, the Garo who live in Meghalaya, northwest India, and the Tsimane in Bolivia (Han *et al*., 2016; Pelto *et al*., 2010). In a survey of modern Han Chinese university students, 63% said that pre-masticated food had featured in their diet when young (Han *et al*., 2016). Whilst the bioavailability of starch may not be greater, the oral stimulation of amylase is and may be a factor when considering AMY1 duplications of up 20 copies.

2.4.1 Areas for Future Research

The importance of the role of starches in the evolution of humans has possibly not yet been fully recognised. From an archaeological perspective there is a need for more research into the human plant diet and its role in our evolution. There is a significant array of methods that can be used and the exploitation of interdisciplinary research in this area may yield significant benefit.

Future Genetic Research

A recent study that looked for general evolutionary positive selection signals in humans and chimpanzees found many strong signals in humans for neural development between brain function and the nervous system and the carbohydrate metabolism (Haygood *et al*., 2007). These findings would support recent arguments that a carbohydrate diet, rather than just meat protein, provided the energy required for human evolution. Further research in both primates and humans would enhance understanding of the evolution of the human carbohydrate metabolism.

Further research into the dietary genetics of ancient fossils is needed to help understand how people migrated and adapted to new environments such as the people who were among the first populations to migrate into America, known as the Clovis people. Did they still have a starch adaptation in their AMY copy

numbers or had they spent sufficient time in the harsh environments of the Boreal Zone and Arctic tundra that they made dietary adaptations to fat? Is it possible to compare the dietary genetics of the Clovis child remains with the remains from the Yana Valley site in Northeastern Siberia, on the Asian side of the Bering land bridge (Pitulko *et al*., 2004; Rasmussen *et al*., 2014)? Would that give an idea of the time taken for this migration to happen?

There is also only AMY genetic evidence from one Neanderthal and one Denisovan. The quality of the DNA is an issue and read depth (the coverage or depth in DNA sequencing is the number of unique reads that include a given nucleotide in the reconstructed sequence (Sims *et al*., 2014), is important, but a better understanding of potential dietary adaptations in these species will help understand how humans varied.

Future Gut Microbiome Research

A major area of future research will come from further advances in understanding the relationship between our biology and diet. There has been an escalation in research into the importance of our gut microbiome. Different organisms that live within the human gut can support the bioavailability of foods, which have helped humans to adapt rapidly to different environments and ecosystems (Moeller *et al*., 2014; Warinner *et al*., 2015). Recent research suggests that, since our evolutionary divergence from the great apes, modern day urban humans have decreased gut microbe diversity compared with gorillas and chimpanzees but have increased in abundance those microbes that accommodate a diet higher in animal foods (Moeller *et al*., 2014). Compared to primates, the human gut microbiome has the greatest similarity with omnivorous New World monkeys (Schnorr *et al*., 2014; Schnorr *et al*., 2016b).

Further dietary research with the Hadza showed that they have a very different gut microbiome from people living in an urban environment. The Hadza completely lack *Bifidobacterium* (associated with a diet that includes dairy products) and enrichment of bacteria such as *Prevotella* and *Treponema* considered to enhance the bioavailability of nutrients from fibrous plant foods. There was also a

difference in gut microbial composition between the sexes, which was inferred to reflect the sexual division of labour and foraging (Schnorr *et al*., 2014). Two studies of the circum-Arctic Inuit demonstrated populations rapidly drawing closer to the dietary habits of urban communities, by the inclusion of gut bacteria associated with higher fibre diets such as *prevotella* (Girard *et al*., 2017). In one study the Inuit were indistinguishable from the people of Montreal who were included in the research (Girard *et al*., 2017). Increased quantities of carbohydrate and lack of seasonality were conclusions in both studies (Dubois *et al*., 2017; Girard *et al*., 2017). A further study based in Peru, compared an extant hunter-gatherer community, the Matses, and an agricultural community, the Tunapuco. The Matses live 150 m asl in an area of hyper-diversity and have been isolated geographically, socially and historically. This community subsist primarily on gathered tubers, manioc (*Manihot* spp.) and plantain (*Musa* spp.). Their protein comes from fish and rare game, such as monkey and small deer. The Tunapuco occupy the Central Andes, 2,500-3,100 m asl and live on a diet of farmed potatoes (*Solanum tuberosa*) and root tubers such as oca (*Oxalis tuberosa*) and mashua *Tropaeolum tuberosum*). Meat such as guinea pigs is reared and fruit and meat are also brought in (Obregon-Tito *et al*., 2015). Both communities exhibited enriched *Treponema* bacteria and showed greater diversity than the comparative US city of Norman (Obregon-Tito *et al*., 2015).

Research into ancient human microbiomes through analysis of mineralized faecal matter is difficult. The high biological activity of faecal matter means that it decomposes very rapidly, and so it is difficult to find unless it is preserved by mineral deposit, which protects it from both decomposition and environmental contamination (Warinner *et al*., 2015). However, the case studies above demonstrate that in human evolution, it is not yet understood how important the role of the gut microbiome has been in helping humans adapt to new environments and ecozones. Had the gut influenced human genetic adaptation and if so how? The Canadian Inuit, for example, who typically have low salivary amylase copy numbers (Inchley *et al*., 2016), today display enriched Treponema gut bacteria, which supports the digestion and bioavailability of nutrients from fibrous plant food (Girard *et al*., 2017). Is this a prelude to a genetic adaptation?

2.5 Conclusion

Human biology and genetic research indicate a significant adaptation to starch consumption from the earliest time of the *H. sapiens*. The genetic amylase duplications are calculated to *c*. 300 kya in Africa, the Middle Stone Ages. Based on current research findings, humans are unique in the extent of this genetic adaptation in comparison with great apes and other archaic human species such as Neanderthals and Denisovans. The duplication of the AMY1 salivary amylase gene from two copies to six represents a strong selective sweep that was fixed before modern humans dispersed out of Africa. Once humans left Africa, however, there were further duplications and deletions of AMY1 in particular but also pancreatic amylase genes AMY2a and 2b. These adaptations are interpreted as a response to climate and food availability in different environments in different latitudes. The global archaeological evidence for hunter-gatherer starchy plant diets is discussed in Chapter 3. The full impact of agriculture on human genetics is not yet clear. Simple and regional adaptations such as lactose persistence and fructose tolerance are associated with agriculture and domestication.

The drivers for the starch digestion genetic adaptations are unknown. Hypotheses have favoured the human ability to cook and thereby extend the range, quantity, palatability and safety of starch plant foods, thus stimulating the need for greater starch digestion capacity.

It is suggested here that, whilst not excluding the above, the role of amylase in increased fertility and successful rearing of children may be an even stronger selective pressure.

Chapter 3

Plant Remains in the Archaeological Record

3.1 Introduction

The identification of evidence of human consumption of starch in the archaeological record is difficult. In Palaeolithic archaeology, meat 'consumption' is inferred from vertebrate remains and stone tools and their association with hearths; for example, the mammoth and reindeer hunting of the Palaeolithic in the Moravian Gates region of central Europe (Svobodá *et al*., 2005). Plant consumption can also be inferred from certain types of stone tools but the evidence of harvesting and processing plant foods and animal husbandry is the most common signal of the advent of agriculture (Hillman, 1981; Marciniak *et al*., 2017). Direct evidence of diet comes from rare archaeological human remains: either mummified remains as with the Neolithic body that was conserved in ice and whose last meal was reconstructed from the stomach contents (Oeggl *et al*., 2007); or ancient human faecal matter, where seeds and lizard scales had passed whole through the digestive process and gave an indication of diet (Reinhard, 2000).

The proxy methods for reconstructing ancient diets are better developed for detecting proteins and lipids than those for dietary carbohydrates (Brown and Brown, 2011). Vertebrate remains and isotope analyses provide a detailed picture of past protein diets, whilst a mixture of gas chromatography and mass spectrometry, and occasionally liquid chromatography, provide information on fats, oils, waxes, steroids and resins, most frequently from ceramic residues (Brown and Brown, 2011). The options for detecting a carbohydrate diet in the archaeological record are limited.

This chapter will review the methods used for recovering plants from the archaeological record. These are divided into three categories: (a) microfossils, not visible to the naked eye, including pollen, phytoliths and starch granules, usually taken from sediment samples; (b) biomolecular and chemical assays which include the detection of plant waxes in sediments and pottery, and carbon stable isotope analyses of bones, both animal and human; and (c) macrofossils, visible to the naked eye, that include charred, mineralised, desiccated or waterlogged plant remains such as wood, seeds, nuts and parenchyma (the tissue that contains the starch food of a plant, generally found in seeds and underground storage organs such as roots, tubers, bulbs, corms, rhizomes). This chapter will also detail the plant anatomy from which are derived the plant tissues that may be conserved, and how these are categorised for sorting and identification.

The successful recovery of botanical remains is dependent upon the preservation conditions in which they are found. This chapter will start with a brief description of the various preservation conditions and of which botanical remains might be preferentially preserved.

3.2 Processes of Archaeobotanical Preservation

Organic plant macro-fossils do not preserve in soils and sediments unless the bacterial and fungal activity is excluded completely or inhibited. Microbial activity is halted by the oxygen-excluded or oxygen-reducing conditions, called anaerobic or anoxic (French, 2003). These conditions are most familiarly encountered in waterlogged sediments. This is one of the best preservation methods and has been responsible for the extraordinary discoveries at the Epi-Palaeolithic site Ohalo II in Israel (23 kya) and the Bronze Age site of Must Farm (Flag Fen), England (3.3 – 2.9 kya) (Malim *et al*., 2015; Nadel *et al*., 2004; Weiss *et al*., 2004).

Aerobic sediments, *i.e*. where oxygen is present, are found in the majority of archaeological conditions. In these conditions, there are three ways that organic remains are preserved. The first is by desiccation, where the exclusion of liquid water inhibits microbial activity (Weiner, 2010); the second and most common is

as carbonised material, where the plant remains have been burned and the cell structures are conserved as carbon; and the third is when uncarbonised plant remains survive where mineral replacement has taken place .

Microbial activity is dependent upon water and near-pristine preservation can be found in very arid conditions, cold or hot, but where liquid water does not reach the plant remains and they become desiccated (Weiner, 2010). Without water, the microbial activity is inhibited in organic material, whether in plants or humans. The arid and mineral sand conditions of the Atacama Desert were used for natural mummification of the dead by the early Chinchorro people, a preceramic fishing society of Southern Peru (9-3 kya) (Arriaza, 1995). Similarly even fragile plant tissues are preserved in fine detail (van der Veen, 2007). Lemmas and paleas of cereals and the papery tunics of garlic (Figure 3.1) have been recovered that look like their modern equivalent, although sometimes cereal grains can be hollow (van der Veen, 2007).

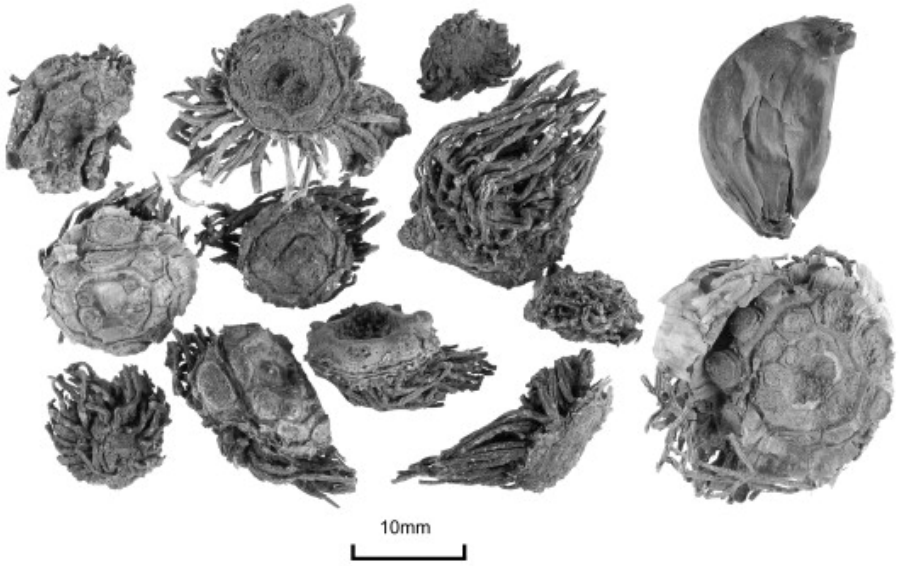


Figure 3.1: Desiccated base plates and clove of *Allium sativum* (garlic) from Mons Porphyrites (mid-late 2nd century AD). Image taken from van der Veen (2007: 972)

These assemblages can come from stored foods, residues of crop processing, animal dung, fodder and bedding, decaying building materials and table waste and hearth sweepings (van der Veen, 2007).

The plant remains densities of such assemblages are usually high with a ten litre sample producing nine litres of plant remains reported from Qasr Ibrim, Nubia, Egypt (3-1.8 kya) (van der Veen, 2007). Such plant remains have provided insights into daily food preparation, consumption, spatial patterning, animal fodder and storage. In the case of storage, detailed inventories of pre-Hispanic granaries from El Álamo-Acusa, Gran Canaria (0.6-0.8 kya) have been possible (Morales *et al*., 2014).

Waterlogged and desiccated preservation is rare and whilst the whole grain, seed, pulse or fruit pip might be preserved, sometimes at a microscopic level, the cell structure is far from perfect (Weiner, 2010).

Charred plant remains are preserved as carbon and will survive in most soil and sediment conditions (French, 2003). However, fossil charcoal suffers from the repeated wet/dry conditions that are often found within caves. Wet/dry conditions have two key negative impacts on preservation. The first is connected with the hydrolysis process: the reaction of hydrogen ions of water and ions in other solutes passing through the sediments and into the charcoal (French, 2003). This means that a solute such as calcium carbonate can form crystals in the charcoal cavities and in some cases cause the charred remains to become hydrophilic. In turn, this can mean that the charcoal disintegrates in flotation. Secondly, these remains can be vulnerable to oxidising conditions that degrade charcoal over time. Oxidation converts charred material that is relatively hydrophobic into a charged hydrophilic material meaning that, again, charcoal will disintegrate on contact with water (Weiner 2010: 182). Charcoal is also fragile and susceptible to mechanical fracture, particularly trampling (Wadley, 2012).

These plant remains, however, have provided a wealth of information about the human relationship with plants, from fuel choices, food, animal fodder, land use and environmental reconstruction. As examples, the study of wood degradation in charcoal prior to burning highlighted that Neanderthals of Abric del Pastor and El Salt, Spain were collecting dead wood for fires 52 kya (Vidal-Matutano *et al*., 2017) and the study of charcoal not only enabled the reconstruction of the

vegetation of terraces in the French Pyrenees but highlighted the use of fire in the creation of these Bronze Age terraces (Bal *et al*., 2010).

Where organic remains are not carbonised, they can be preserved in aerobic conditions by a process of mineralisation, where organic tissue is replaced by minerals (McCobb *et al*., 2001). These minerals can vary according to the plant mineral composition and the archaeological context. Seeds, for example, appear to be most often replaced with potassium hydroxide and calcium phosphate, and plant remains found in latrines and in faecal matter have replaced organic remains with calcium phosphate; calcium phosphate being a constituent present in faeces (Baeten *et al*., 2012; McCobb *et al*., 2001). This mineralisation may also take place in caves, where calcium carbonates and phosphates can co-exist (Martinoli, 2004).

Micro-fossils can be extracted from most environments but are not immune to the nature of the preservation conditions. Pollen appears to be optimally preserved in more acidic conditions (French, 2003), although through adaptations in recovery methods, pollen has been recovered extensively from basic/calcareous cave environments (Hunt and Fiacconi, 2018). Phytoliths are robust and appear to be able to survive most preservation environments (Piperno, 2006). Starch granules have been purportedly recovered from a number of differing contexts but there is no clear explanation about how starch granules are preserved. This is considered below.

3.2 Plant Micro-fossils

This section will consider the difficulties associated with the recovery and analysis of plant micro-fossils preserved in the archaeological record.

Micro-fossils can move through the stratigraphy with water action and bioturbation. Burrowing animals and plant root systems can cause mixing of the horizons (French, 2003). The interpretation of micro-fossils, especially where it is difficult to differentiate ancient from modern, is dependent on tight taphonomic control (Mercader *et al*., 2018). In a sediment column, for example, the upper

layers may be peat developed on podzols that would be good conditions for pollen preservation. But these conditions may not always have been present and in the lower layers of a sediment column the deposition and preservation conditions may be quite different (French, 2003).

Research into phytoliths and starch granules has focussed on actualistic experiments such as adding loose phytoliths to a soil column to see how they move through the sediment column (Pearsall, 2015). In the case of starch granules, stone flake tools were used to cut sweet potato and were both the tools and sweet potato were buried and left in the open for two years and afterwards assessed for starch granule survival. The open air samples showed little survival of starch granules but better preservation of starch granules was evident on the buried stone tools (Barton, 2009). While useful, these experiments cannot reflect the complexity of deposition, preservation and recovery.

3.2.1 Pollen Analysis

Pollen grains are the male micro-gametophytes produced by seed plants, angiosperms and gymnosperms (Pearsall, 2015). Pollen grains released by plants are either carried on the wind, which then fall on land and water or, because the larger sized pollen grains are too heavy to be carried on the wind, they simply fall within the immediate environs of the plant (Pearsall, 2015). The taxon specific morphologies and the distribution habits together with the accumulation of pollen in soil horizons over time gives a general representation of the vegetation and from that the climate and any changes through the sequence of the sample. The samples are preferably taken from permanently wet areas such as bogs, lakes, ocean floors (Pearsall, 2015), or even ditches but have also been taken successfully from caves (Hunt and Fiacconi, 2018), coprolites (Horrocks *et al*., 2003) and from burials (Leroi-Gourhan, 1975). The outer casing of pollen grains (exine) is particularly resilient and it allows the grains to survive, particularly if undisturbed for long periods of time (Pearsall, 2015).

Pollen analysis is most often used to reconstruct past landscapes, vegetation and environments, to detect significant climate change and large scale human impact

on those environments. Large scale human impacts have included swamp forest clearance for rice cultivation (6kya) around Niah Cave, Sarawak, Borneo (Hunt and Rushworth, 2017) and disruption of humid forest steppe landscape at Wadi Faynan, Jordan by early Holocene farmers around 8.1 kya (Hunt *et al*., 2004). Pollen analysis was also used to understand better the impact on the vegetation of the Last Glacial Maximum on the Western Cape of South Africa (Parkington *et al*., 2000).

But pollen has also been useful in smaller scale contexts such as the identification of flowers in a Neanderthal burial in Shanidar Cave, Iraq (Leroi-Gourhan, 1975). Pollen analysis in palaeo-diet reconstruction, however, is limited. The presence of pollen in coprolites or in a mummified colon does not signal food consumption necessarily, and it is difficult to differentiate between intentionally consumed and unintentionally ingested (*i.e*. through inhalation of air-borne pollen). Concentrated, elevated levels of pollen from a particular bee-pollinated species, *i.e*. lime trees (*Tilia* sp.) might signal the consumption of honey (Brown *et al*., 2017).The colon of the late Neolithic ice man preserved in ice (5.3 kya), conserved ingested pollen. However, much of this came from wind-pollinated trees and plants that would exclude the consumption of honey and none of it in sufficiently concentrated quantities that would suggest pollen was consumed as a food. The presence of catkin-bearing hop hornbeam (*Ostrya carpinifolia*) however, suggested that he had unintentionally ingested the pollen, probably through drinking water on which the pollen had settled, in the late spring/early summer in the valley, prior to climbing to 3000 metres above sea level (msal) where he died (Dickson *et al*., 2000). By contrast, analysis of a medieval cesspit in Riga, Latvia, constructed in 1201 AD but in use until the 16th century, indicated that high concentrations of lime (*Tilia* sp.) pollen indicated the use of local honey. The other pollen species were consistent with cereal crops, oats (*Avena* sp.), wheat (*Triticum* sp.) and small amounts of rye (*Secale* sp.) and barley (*Hordeum* sp.), supported by high proportions of field weeds. High levels of pollen from Brassicaceae might relate to edible taxa and high frequencies of *Rubus* pollen attest to the probability of bramble/raspberry (*Rubus* sp.) and possible blackcurrant (*Ribes nigrum*) consumption (Brown *et al*., 2017).

Pollen is a generally a landscape scale tool, unless it can be used in very specific contexts such as coprolites/cesspits/latrines, burials or mummified remains. Pollen would not provide evidence of cooking as heat destroys pollen grains (Pearsall, 2015) and as a stand-alone method would exclude direct evidence of the use of roots and tubers, although it may identify root and tuber bearing plants.

3.2.2 Phytoliths

Phytoliths is a term, *sensu stricto,* that refers to all the minerals produced by plants. These include calcium oxalates, calcium carbonates, silica, calcite, aragonite and vaterite and various organic crystals (Weiner, 2010).

However, in archaeological research, phytoliths describe the microscopic deposits of silica that are formed when the plant takes up groundwater containing monosilicic acid. The plant deposits this silica in all parts of the plant and the bodies are formed with the transpiration process and a higher density of phytoliths are found in upper parts of the plant (Piperno, 2006). These opal or glass micro-fossils retain the cell shape when the organic tissue has decayed or been burned. And because these fossils are inorganic, they preserve well in the archaeological record (Piperno, 2006)

Phytolith morphologies can often, but not always, be identified to genus and species level and can definitely be identified to the part of the plant from which they came. Phytoliths are predominantly produced in the large plant group – Poaceae (grasses), which includes all cereals, and are also formed in pteridophytes (ferns), leaves from dicotyledonous plants (all flowering, angiosperm plants), wood and bark (Piperno, 2006; Weiner, 2010). Because of their distinctive morphologies and the fact that silica does not decay, phytoliths have enabled archaeobotanists to recreate the vegetation in prehistoric landscapes (Albert and Esteban, 2016), and to differentiate between grasses used for bedding (Wadley *et al*., 2011) and those plants used for fuel or food, for example by identifying phytoliths from the panicles that would have held wild grass seeds (Albert *et al*., 2003; Albert *et al*., 2012; Madella *et al*., 2002). They have also allowed archaeologists studying historic times to distinguish between ploughed fields and

grasslands and to understand human activities within city walls (Devos *et al*., 2009).

Phytoliths recovered from sediments, dental calculus, coprolites and cooking pots have provided significant knowledge in the reconstruction of diets from archaic hominins, Neanderthals and humans (Albert and Esteban, 2016; Chandler-Ezell *et al*., 2006; Henry *et al*., 2012; Horrocks *et al*., 2003; Lalueza Fox *et al*., 1996; Madella *et al*., 2002).

Recent phytolith research has helped to increase knowledge about the environments and possible diet of the early species of *Homo* such as *H. habilis* (Albert and Esteban, 2016). Beds I and II from Olduvai gorge represent the period when these early hominins would have been roaming this area of Tanzania. Albert and Esteban's study aimed to recover plant artefacts from combustion features (potential hearths) and to identify those plants that could have been part of their diet, particularly roots and tubers (Albert and Esteban, 2016). Using FTIR (Fourier Transformed Infrared Spectrometry), this study identified both crystalline and amorphous materials, allowing them to isolate phytolith-rich levels and to determine if the sediment had been thermally altered (burned) (Albert and Esteban, 2016). With a model in place to control for post-depositional effects on the phytoliths, the results identified a very different environment around Olduvai Gorge than previously understood. During the time of these archaic hominins, the landscape would have been significantly more humid with a fluctuating saline-alkaline lake, fresh water courses, marshlands, shrubs and trees. Phytolith and silicified macrofossil evidence of palms and sedges in the environment suggests that these starchy foods were certainly available during this period (Albert and Bamford, 2012; Bamford *et al*., 2008; Blumenschine *et al*., 2012).

Phytoliths are formed through the loss of water through transpiration, so although water containing monosilicic acid is taken up by green plants and supplied to fleshy roots and tubers, almost no phytoliths form in underground storage organs (Piperno, 2006). Phytoliths would be present in grass seeds, but as yet there is no evidence of grass seeds being cooked (Nic Eoin, 2016). This presents a limitation to this method for this research.

3.2.3 Starch Granules

There is now a large body of evidence for starch granules from three depositional processes: a) sediments from archaeological layers associated with anthropogenic activity; b) stone tools and grindstones and; c) fossilized dental calculus from human and Neanderthal remains. There are two fundamental issues with the use of starch granules as evidence: firstly, how do starch granules survive in the archaeological record? and secondly, how are ancient starch granules distinguished from modern granules (Mercader *et al*., 2018)?

How do starch granules survive? From an archaeological perspective, none of the mechanisms that slow amylase hydrolysis offers an explanation for archaeological preservation of starch granules over thousands of years. Yet starch remains and residues have been reported from archaeological contexts laid down thousands of years ago. This suggests that, in some way, the normal hydrolysis process has been interrupted. Yet there is still no demonstrable understanding of the preservation pathways. The archaeological samples have come from soils and sediments, stone tools, grinding stones, coprolites, fossilized dental calculus and, from the advent of agriculture onwards, from pottery and food remains (Crowther, 2012). However, there has not always been adequate explanation of the deposition or preservation processes or often the methods used in the analysis and Mercader *et al*. have recently defined areas of research concerned with both authenticity and taphonomy (Mercader *et al*., 2018).

Soils and Sediments

The argument for analysis of starch granules from soil/sediment samples taken from archaeological sites is that there may be residues from the processing and consumption of starchy plants at the site in the past (Barton, 2005).

It is important to distinguish between soils and sediments. Soils are active products of weathering processes upon organic matter, minerals, water and gases (Frey, 2007). Biodiversity in soil is governed by the pH, which is a measure of the acidity

or alkalinity of a soil. Most soils fall between 3 and 10 on the pH scale, with 7 being neutral. Acidic soils, which tend to reduce bacterial numbers, have a pH below 7. Alkaline soils, which tend to reduce fungal numbers, have a pH above 7. The main factors that influence the pH level are the nature of the bedrock and the environment. In warm humid environments, bedrock can be weathered by water moving downwards through the soil, creating acidic conditions. In dry climates, weathering and leaching are less likely so the soil is often neutral or alkaline (van Breemen *et al*., 1983). Both bacteria and fungi can express both alpha and beta amylases to hydrolyse plant starches in soils (Bertoft, 2017). In the rhizosphere, the surface depth occupied by plant roots, a mixture of macro-fauna, which includes earthworms, woodlice, centipedes, beetles, slugs and snails and meso-fauna that includes tardigrades and lice, consume plant remains and starch granules in the soil (Brown and Brown, 2011; Frey, 2007; Voronay and Heck, 2015). Unless the soils are compacted, eliminating oxygen and voids, and buried, it is hard to see how starch granules would survive for long in this environment.

Sediments are naturally occurring minerals that have been broken down by erosion and the particles transported by wind or water. Sand, for example, can be transported by wind, seas or rivers (Prothero and Schwab, 2004). Unless soils form within them, they are not active but they can be wet, which would cause starch granules to swell and deteriorate. In arid, desert conditions, it is easier to envisage how starch granules might survive. The sediments in caves can be subject to both processes. Periods of occupation might accumulate layers of organic material but periods between occupation may see cave processes of sedimentation. Bioturbation can cause significant mixing and starch granules found in these environments would need very careful explanation and analysis.

Stone Tools and Grindstones

Tantalizingly for deep time starch research, starch granules have been reported from stone tools from early *H. sapiens* in Niassa, Mozambique at around 150 kya (Mercader *et al*., 2008), and the Sai Island, Sudan 150-200 kya (Van Peer *et al*., 2003). But research has yet to address three key questions. How did the starch grains survive this long? How has contamination in the process been avoided?

How have new starch granules been distinguished from ancient granules? Mercader *et al*. (2009) offer evidence of differences in amylolysis (the conversion of starch to simple sugars by amylase enzymes) in steam-flaked sorghum and in starch granule porosity (Harbers, 1975; Sujka and Jamroz, 2007), the first of which speeds amylolysis and the second slows it. The arguments for preservation of starch granules on tools and grindstones have been that: (a) the micro-environment has in some way offered protection from hydrolysis from bacteria and fungi in particular; and (b) that there is some protection generated by a chemical interaction offered by the artefacts with which the starch granules are associated (Barton and Matthews, 2006).

The key issue with analysis of tools is contamination. Starch granules vary in size between 0.1-200 μm and their weight matches that of pollen. Therefore, like pollen, modern starch granules are airborne and a very likely contaminant in any process. They attach to clothes and hair, they enter through ventilation systems and even from 'clouds' of starch granules created by research within a laboratory. They are part of the production process of laboratory gloves (even powder-free gloves), paper and cardboard. In a study to examine potential sources of modern contamination, it was found that more than 75% of the contamination came from airborne starch granules from a variety of species (Crowther *et al*., 2014). In what has proved to be a seminal methods paper, the importance of establishing the background starch granule 'noise' by setting slide 'traps' is crucial to any study, along with understanding the right products and processes for cleaning laboratories and removing samples to be analysed from the tools. The publication of that paper has had the effect of raising the standards in this field and a recent publication has outlined future areas of research in this discipline that would allow the verification of authenticity (Mercader *et al*., 2018).

Dental Calculus

A potential preservation pathway for starch granules in dental calculus is more easy to envisage. Human saliva contains a starch-digesting enzyme called amylase. Food compaction and poor oral hygiene produce a plaque biofilm over the teeth and layers of plaque build-up to form calculus, which can become as hard as bone

(Hardy *et al*., 2009). Starch granules can become trapped within the plaque biofilms and calculus, which form a barrier from the amylase enzyme (Hardy *et al*., 2009). This method offers insights into the potential deep time dietary habits of both humans from South Africa and the Middle East 33-130 kya and Neanderthals from Europe and the Middle East 40-100 kya (Henry *et al*., 2014).

There remain two issues with this method. There does not appear to have been any debate about the potential for starch granules entering dental calculus through an airborne pathway, like pollen. Whilst airborne starch granules are now screened in laboratories as a matter of course, pollen and starch granules that enter the mouth whilst breathing are not discussed. A discussion on starch granule size and its likely pathway into this context needs further examination. The second issue is one of interpretation: starch granules in dental calculus can provide an indication of presence/absence only and cannot be interpreted as an indication of widespread diet. Experimental research with living foragers, the Twe in Namibia and Angola, compared the analysis of starch granules and phytoliths found in the dental calculus with the known range and intensity of their dietary plant consumption. The outcome demonstrated that starch granules and phytoliths are poor predictors of plants consumed. Of the nineteen starchy plants eaten by the Twe, only six were found in the starch granules and four in the phytolith assemblages (Leonard *et al*., 2015). Further research of this kind is needed.

How are Ancient Starch Granules Distinguished from Modern Granules?

The key challenge is that it is not yet possible to direct-date starch granules or distinguish the ancient from the modern as with pollen grains and phytoliths. If there has been contamination at any point in the collection, processing or analysis, it would be difficult to know. In a recent critical review of starch granule research, new methods and standards are offered that would better support starch research (Mercader *et al*., 2018).

The improved and ever improving methods of extraction and identification of microfossils in dental, residue and artefact analysis are opening up avenues of

investigation that offer significant benefits in understanding early human diet, especially in synthesis with each other and with existing archaeological methods.

3.3 Chemical and Biomolecular Methods

3.3.1 Isotopes

Carbon isotopes enter the food chain when plants photosynthesize carbon, creating food for the plant in the form of glucose. The isotopic composition of the plant source varies according to the type of photosynthetic system the plant used. There are three photosynthetic systems whereby plants fixes carbon dioxide: C3, C4 or Crassulacean acid metabolism (CAM). C3 plants thrive in temperate climates, whereas C4plants belong to a restricted range of families and grasses that have an additional metabolic pathway adaptation to higher temperatures and greater aridity (Weiner, 2010). CAM plants have a photosynthesis method adapted to arid conditions that allows the stomata to close during the day to minimise evapotranspiration but open at night to collect carbon dioxide. Pineapples are an example of a CAM plant (Dodd *et al*., 2002). The consumption of these different plants will affect the Carbon 13 values in the body tissues of the animal, which can be measured, either from bone collagen or in the hydroxylapatite of teeth and bones. Carbon and nitrogen stable isotope analyses can be made from samples taken from pure bone collagen, with nitrogen selecting for protein and carbon indicating the plant photosynthesis pathway in the trophic chain. However, carbon signals can come either from the consumption of plants or the consumption of animals that have eaten those plants (Lee-Thorp *et al*., 1994).

This method has been successful in tracking archaic hominin diets that included C_3 plants, in an African environment generally dominated by C_4 based plants and the extent of the C_3 plant diet (Cerling *et al*., 2011; Henry *et al*., 2012; Peters and Vogel, 2005; Sponheimer *et al*., 2005a; Sponheimer *et al*., 2005b; Sponheimer *et al*., 2013; Wynn *et al*., 2013; Wynn *et al*., 2016;).

Multiple archaeobotanical methods were used with the discovery of two fossilised individuals of *Australopithecus sediba* (2 ma), from Malapa, 45 km from

Johannesburg, South Africa. *A. sediba* is an early hominin that, whilst classified as an Australopith, also has morphological traits that align it with *Homo* species (Berger *et al.*, 2010). The environmental data for this site come from pollen and carnivore coprolite analysis and indicate a forest environment, and the phytoliths from the hominin layer indicate savanna with C4 grasses in summer rainfall areas. The stable carbon isotope analyses of these two individuals, however, indicate an almost exclusively C3 diet but this isotope reading could also be explained by the consumption of animals that also ate these plants (Henry *et al.*, 2012). The analysis of phytoliths trapped in the fossilised dental calculus suggests that these Australopiths preferred to eat grasses or sedges. This evidence contrasts with data for other hominins in the region (Henry *et al.*, 2012), and further direct diet research is needed to provide regional variation to the very broad brush picture painted by isotope data.

Stable isotope ratios of carbon and nitrogen have been used to recreate palaeodiets of other archaic hominins, as well as Neanderthals and early humans. They have been very successful in reconstructing the protein content of the diets in particular (Richards, 2009; Richards *et al.*, 2000; Richards and Trinkhaus, 2009). Isotopes have been able to distinguish whether the dietary protein came from marine or terrestrial sources and can distinguish between plant or animal sources and fresh or marine water sources (Richards, 2009).

In general, early studies have led to statements about human Upper Palaeolithic diets in Europe such as "Plant foods were not an important part of diet, at least in terms of dietary protein, which means that gathering protein-rich plants like hazelnuts was unlikely to have been an important subsistence activity in the Upper Palaeolithic, at least for the humans measured here" (Richards 2009: 256). The image that early modern humans in northern latitudes were predominantly meat-eaters, created by analysis of faunal remains and stone tools, has been reinforced by the enthusiastic interpretation of isotopic studies. The analysis of combined carbon and hydrogen isotopes can identify the isotopic composition of n-alkanes in plant leaf waxes but this does not reflect starches and would be of limited value in reconstructing past diets (Bi *et al.*, 2005).

3.3.2 DNA

The Bering land bridge that connected Asia with North America during the glacial periods is the most likely route by which humans entered the Americas (Pedersen *et al*., 2016; Raghavan *et al*., 2014a; Raghavan *et al*., 2014b; Rasmussen *et al*., 2015). The resolution of many of the questions raised through conflicting dates in North and South America and some genetic affiliations with Polynesia were resolved through ancient human DNA analysis (aDNA). The Bering land bridge was exposed largely during glacial periods when ice and cold would have prevented humans crossing this isthmus. Amelioration of the climate and retreating of the ice sheets sufficient to have allowed humans to cross, but before the sea covered the bridge, would have offered a window previously estimated between 13-14 kya, when the first evidence of humans appears in America (Pedersen *et al*., 2016). Environmental DNA (eDNA) was used on cores taken from Charlie Lake at a bottleneck on the isthmus and used a combination of pollen and eDNA to identify plant species (Pedersen *et al*., 2016). The combined analyses identified grasses and sedges which colonised the lake area ~12.6-11.6 cal. kya, with evidence of steppe vegetation including *Artemisia* sp. (sagebrush), Asteraceae (sunflower family), Ranunculaceae (buttercup family), Rosaceae (rose family), *Betula* sp. (Birch) and *Salix* sp. (Willow) (Pedersen *et al*., 2016: 46). It may be that in future, eDNA of block sediments from archaeological excavations will be able to identify plant remains, particularly where humified plant layers remain and correlated with other archaeobotanical evidence.

3.3.4 Lipids and Plant Waxes

Biomolecular methods primarily include the analysis of molecules that diffuse into ceramic vessels where they are protected from degradation. These tend to be lipids, which can be extracted from the powdered ceramic and analysed (Evershed *et al*., 2001).

Gas chromatography and spectrophotometry have been used in an experiment to identify four root crop species from sites in coastal Peru (Ugent, 1994). This

method is more widely used to study residues in pottery, predominantly lipids. More recently, gas chromatography has been used successfully to detect carbon 13 values for plant wax-derived n-alkanes and alkanoic acids in prehistoric ceramic cooking vessels dated to 8,200-6,400 BC. The results indicated a systematic processing of C3 and C4 grasses and aquatic plants, gathered from savannahs and lakes in the early to mid-Holocene green Sahara. When combined with the regional archaeobotanical macrofossil evidence, the study showed consumption of rhizomes, from *Typha* sp., (bulrush) *Cyperus rotundus* (nut grass), and *Bolboschoenus maritimus* (sea club rush), as well as peeled stems, flower spikes and possibly pollen (Dunne *et al*., 2016). It may be a suitable method for analysing grindstones but this is currently a destructive process and grindstones at early human time depths are extremely rare. Whilst there is evidence of charred seeds from many contexts from around the world, there is little evidence to be seen on the seeds themselves of grinding. The oldest evidence appears to come from starch granule micro-fossils and use-wear analysis of a grindstone from Haua Fteah cave, Libya, which suggests seed grinding at c. 31 kya (Barton *et al*., 2018) and from Cuddie Springs, Australia dated to 30 kya (Fullagar and Field, 1997). Three grindstones have been excavated from the Howiesons Poort levels (~65-50 kya) of Cave 1a, Klasies River, South Africa but the results from the analyses have not yet been published.

The detection of α-linoleic acid (ALA) in residues from Qesem Cave pointed to the potential of pine nuts as part of the Neanderthal diet (Hardy and Kubiak-Martens, 2016). This is interesting, but ALAs are important in the debate on meat versus plant foods as a catalyst for brain expansion; DHAs (docosahexanoic acid) is a critical structural component of the brain, retina and other nerve tissues and essential for growth and functional development of the brain in infants. Although meat is a source of these essential fatty acids, they can also be synthesized from ALAs in ocean fish, eggs, seed oils and leafy plant foods (Hardy *et al*., 2015: 8). Evidence supporting the hypothesis that encephalisation was also dependent on high energy foods in addition to the proteins from meat, is improved by the ability to detect these fatty acids. Similarly EFAs (essential fatty acids) that are critical in

pregnancy only come from plants and a method to detect these in future would be an advantage.

3.4 Macrofossils

Macrofossils comprise the preserved plant remains visible to the naked eye, and include: wood, seeds, nuts, fruits, woody stems, leaves, pine cones and needles and underground storage organs (roots, tubers, corms, bulbs and rhizomes) that preserve in the archaeological record. These macrofossils are often charred, but can be mineralised, desiccated or water-logged. They have provided a significant body of knowledge about human: plant interactions and relationships. This section will briefly consider the difficulties associated with the recovery, analysis and interpretation of plant macrofossils preserved in the archaeological record.

Charred macro-fossils are collected by any one of two methods: sediment samples may be wet or dry sieved, using anything from a 0.3mm - 4mm mesh; or water flotation, whereby sediment samples are collected from archaeological contexts, and, using the variation in density between charred organic remains and inorganic material. A sediment sample is poured into water (a flotation tank), where charred botanical remains float to the surface, leaving sediment to sink to the bottom. The charred remains are normally captured in a 1mm and 0.5mm mesh (Pearsall, 2015). The wet sieving may be used on waterlogged material that does not float, whereas dry sieving may be used on desiccated material that would suffer from contact with water. Flotation is an excellent recovery method for carbonised remains from other environments, unless the preservations conditions are as described above.

The evidence for plant macrofossils is covered below but the improved tool kit available to archaeobotanists has helped to advance this field. The use of scanning electron microscopy (SEM) gives a three-dimensional view of remains that previously may have been too small or complex under a stereo-microscope. In the author's experience, the process of stitching together photographs taken on a stereo-microscope has created an artefact where there was none. SEM eliminates this issue.

The single largest contribution of knowledge made by macrofossils has been the story they have told about the human transition from hunting and gathering to agricultural food production. Through macro-fossils, there is now a body of knowledge about plant food diets in pre-agrarian environments (Barton and Paz, 2007; Kubiak-Martens, 1999; Kubiak-Martens, 2002; Paz, 2005b) that also suggests humans continued to gather long after complex agrarian societies had been formed (Behre, 2007). Macro-fossils have enabled archaeobotanists to distinguish production and processing stages in cereal crops (Dennell, 1974; Dennell, 1976; Hillman, 1981; Hubbard, 1976) and when and how plants were domesticated by region (Fuller *et al*., 2014). More recently, macro-fossils have been used to understand when populations adopted certain foods (Yang *et al*., 2016), the migration of people and plant crops (Bates *et al*., 2016; Motuzaite-Matuzeviciute *et al*., 2015) and when, how and what plants people traded in the past (Castillo *et al*., 2016). However, we also have new knowledge on Upper Palaeolithic/Later Stone Age hunter-gatherer plant diets through the study of macro-fossils (Deacon, 1976; Deacon, 1993; Hoffman *et al*., 2016; Kubiak-Martens, 1996; Mason *et al*., 1994; Pryor *et al*., 2013; Weiss *et al*., 2004).

In addition to diet, macro-fossils have given us insights into human decision-making about issues such as fuel (Beresford-Jones *et al*., 2010), climate change (Beresford-Jones *et al*., 2011), cognitive processes, resource knowledge and exploitation (Jones, 2009b) and social organisation as well as human migration (Rademaker *et al*., 2014).

As with all other plant remains, deposition process is key. Wild fires in the landscape can be frequent in some regions and can be accounted for in interpretation (Pearsall, 2015) but distinguishing between different human activities in a single location requires good taphonomic understanding. Charred material can come from burned bedding, hearths, site maintenance such as ash dumps, trampling and occupation levels (Goldberg *et al*., 2009; Mallol *et al*., 2013; Mallol *et al*., 2013b; Mallol *et al*., 2007). The determination of diet through charred macro-fossils requires an understanding of context, either a primary

deposition directly around a hearth, or from secondary depositions in middens (Pearsall, 2015).

In the identification of the starch element of the diet of early human hunter-gatherers, wild roots and tubers may have been the most likely source (Deacon, 1993). Later Stone Age (LSA) evidence, including both charred and desiccated whole corms from a number of caves and rockshelters in South Africa, Melkhoutboom, Strathalan Cave, Highland Shelter and Scott's Cave, attest to the role of roots and tubers in the hunter-gatherer diet in South Africa 30-40 kya (Deacon, 1976; Deacon, 1993; Opperman, 1996). Recent research has also highlighted the increasing body of evidence for the consumption of grass seeds during the MSA of South Africa (Nic Eoin, 2016) but this would not preclude consumption of other seeds, legumes, nuts and fruits.

3.5 Charred Macro-remains - Starch Identification

The nature of the botanical remains from starch plants likely to be recovered from hearth contexts have been classified by the author in Figure 3.2. This section will consider the detailed analysis of charred remains and describe how this enables the identification of their botanical origins.

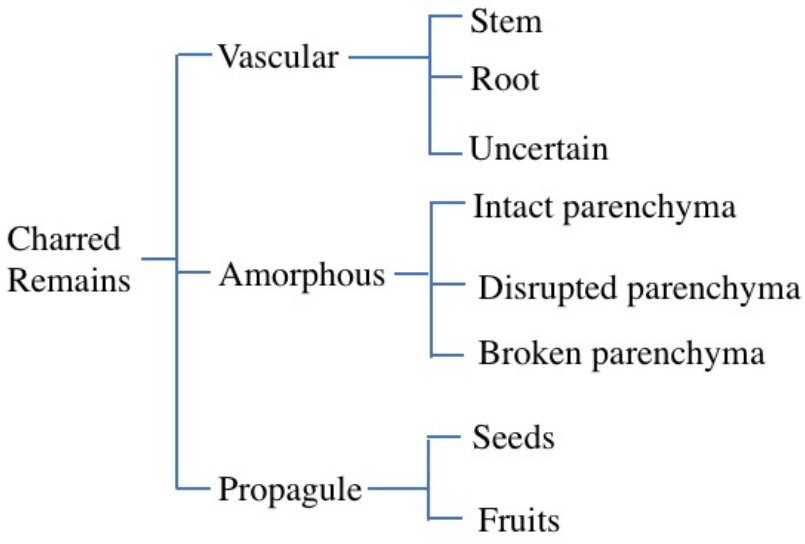


Figure 3.2: Classification of starchy plant macro-fossils.

3.5.1 Vascular Tissue

Xylem is the tissue in a vascular plant that carries water and nutrients upwards from the roots to the rest of the plant. Phloem is the vascular tissue that transports the soluble organic compounds made during photosynthesis in the leaves to the rest of the plant; a process known as translocation; the organic compound being mostly glucose (Dickison, 2000). In a botanical sample, xylem can form a large percentage of the sample. Wood charcoal, a common source of fuel, has a high percentage of xylem. In the vegetative tissue of roots and tubers the anatomy of xylem is more complex but can also be diagnostic.

Taproots

Taproots, such as carrots, are swollen secondary roots of biennial/perennial herbaceous plants. The xylem viewed in transverse section (TS), *i.e.* cross-section, is arranged in a ring around the stele or centre of the root and between the stele (central part of the root or stem) and the epidermis (Hather, 2000) (Figures 3.3 and 3.4). Figure 3.4 is from the modern reference collection gathered from coastal margins at Klasies River.

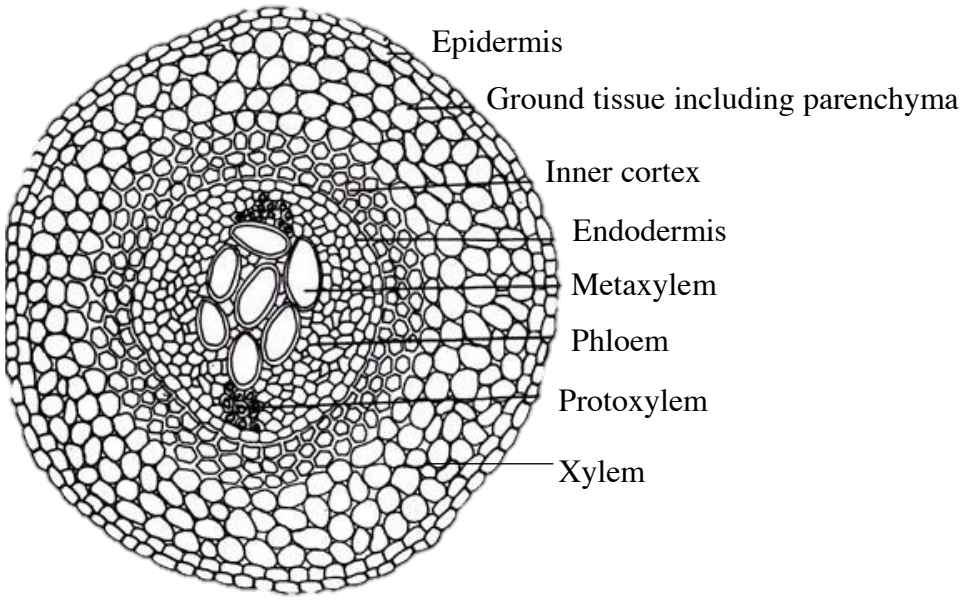


Figure 3.3: Diagram of anatomy of a taproot. (Diagram adapted from Bir and Randhawa (1984) by C. Larbey)

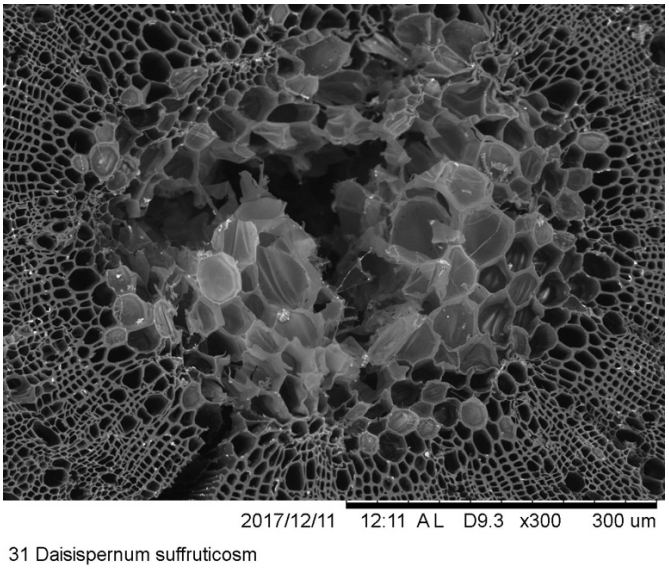


Figure 3.4: *Daisispernum suffruticosm*, Apiaceae (wild carrot). In this figure the metaxylem is burned out but the pith parenchyma can still be seen together with the surrounding phloem and xylem of the inner cortex. (Micrograph: C. Larbey)

Stems

Many underground storage organs are underground stems that provide energy and nutrients for new growth and as a means of asexual reproduction (Dickison, 2000). Tubers, rhizomes, corms and bulbs are all underground stems but with xylem or vascular structures arranged in different ways, dependent largely upon the clade;

monocotyledon (monocot) or dicotyledon (dicot). Eustele, found in dicot plants, is where the vascular tissue is formed in a central ring of bundles around the pith, and atactostele, found in monocot plant, is where the vascular tissue in the stem is scattered in bundles (Figure 3.5).

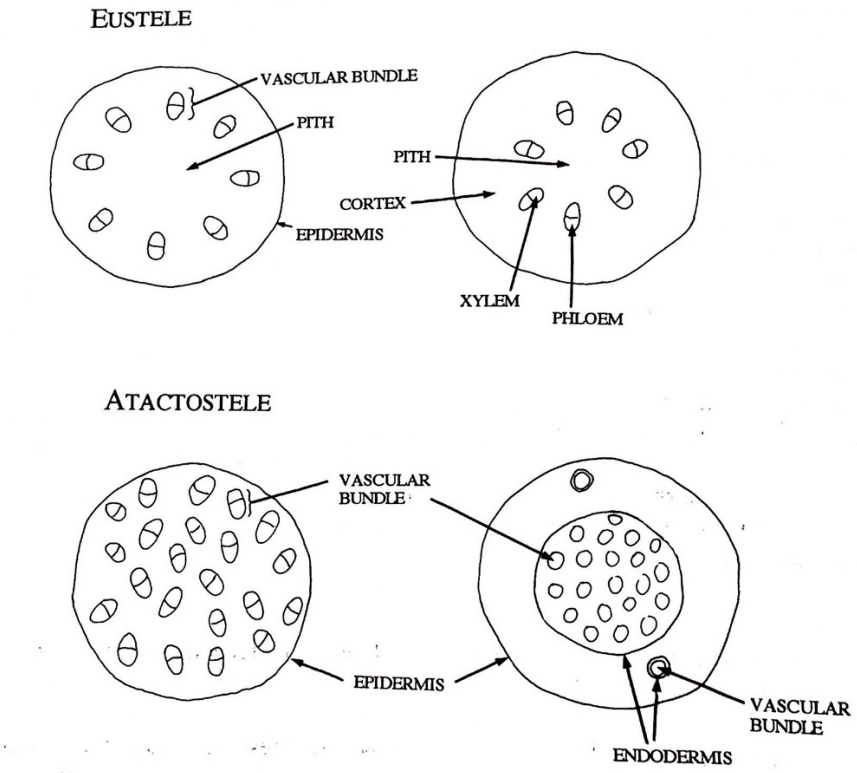


Figure 3.5: Vascular bundles around pith in eustele (dicots) and scattered bundles in atactostele (monocots). Image adapted from Hather (2000: 50) by C. Larbey.

An example of the different vascular arrangements from the charred reference collection created for this research (described later in this thesis) can be seen at Figures 3.6 and 3.7.

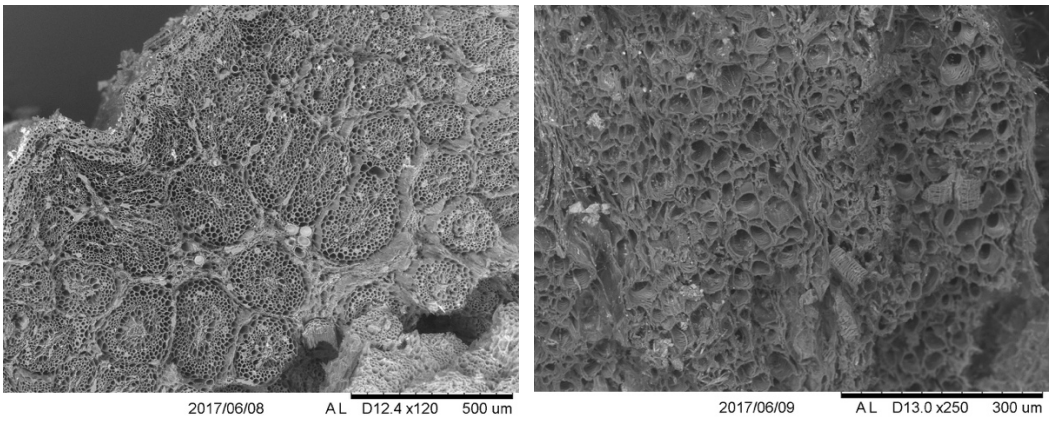


Figure 3.6: Vascular Structures: transverse section (TS) on the left shows the vascular bundles of a monocot (*Juncus puuctorius* - common name: Biesie), where the vessels are grouped together. Whereas on the right, the TS section through a dicot (*Lichtensteinia* sp.), shows a more distributed vascular structure. Both images from the Klasies River modern reference collection. (Micrographs: C. Larbey)

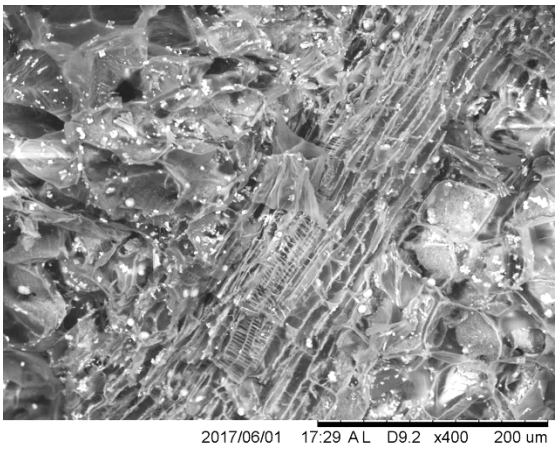


Figure 3.7: Vascular bundle in TLS view (*Chasmanthe aethiopica*) from Klasies River modern reference collection. (Micrograph: C. Larbey)

Uncertain

Some fragments cannot be positively identified; such assemblages can contain unidentifiable xylem; phloem rarely is conserved, and often in transverse longitudinal section (TLS) as in Figure 3.8.

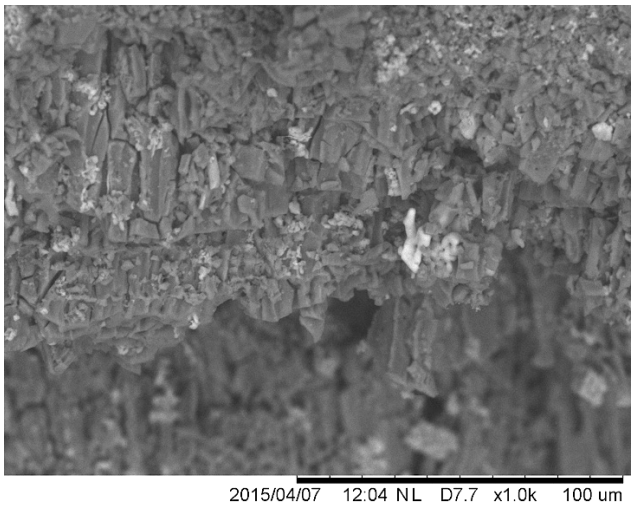


Figure 3.8: Unidentifiable xylem in TLS from botanical assemblage (KR1501F1).

3.5.2 Amorphous

This category comprises parenchymous tissue and its associated features.

Parenchyma

Parenchyma is a relatively undifferentiated tissue that contains the starch granules, the energy source, stored by green plants and used for future growth (Pérez *et al*., 2009; Preiss, 2009) (Figure 3.9). The parenchyma cell walls themselves are made of a polysaccharide (Englyst and Englyst, 2007).

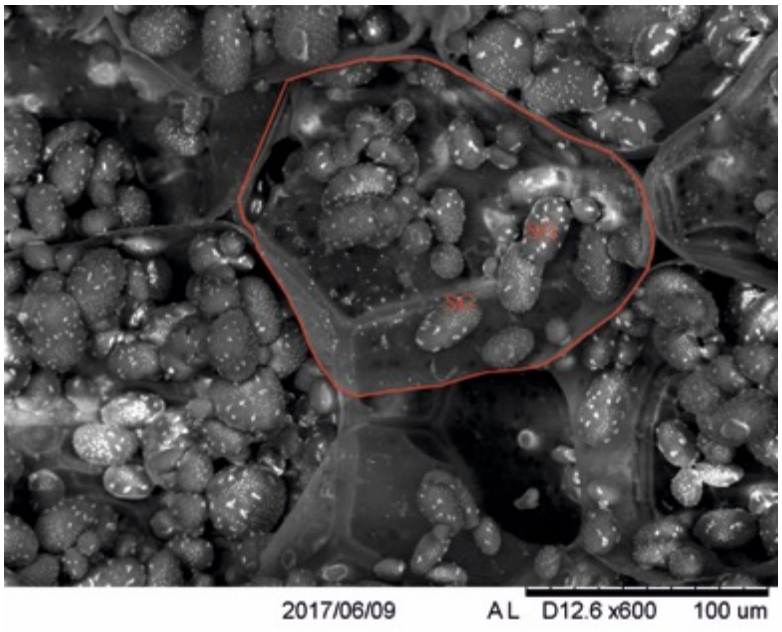


Figure 3.9: SEM of an *Oxalis* sp. bulb with parenchyma (parenchyma cell outlined in red) filled with starch granules (marked with a red SG), from Klasies River modern reference collection. (Micrograph: C. Larbey)

Parenchyma cells can be spherical or isodiametric (Hather, 2000) and an example of the latter can be seen in Figure 3.10

Figure 3.10: Isodiametric parenchyma cells (cut through middle lamella) in TLS from *Haplocapensis nervosa* Asteraceae from Klasies River modern reference collection. (Micrograph: C. Larbey)

Parenchyma cells have no gaps between them and are clearly related to each other, which is not the case for faecal or processed matter (Hather, 2000). Differences in structure were identified and categorised as follows:

Broken Parenchyma

Broken parenchyma is identified as clearly parenchymous tissue but which has been crushed or trampled by a mechanical force post-charring. Very often the fractures are angular and straight-edged.

Disrupted Parenchyma

Disrupted parenchyma cell structure is where the regularity of the tissue is disrupted prior to burning of the tissue structure. There is often a 'folded'

appearance and the cell walls have collapsed inwards. If the cells walls are deformed by escaping steam, then the cell walls are often thickened by carbonisation and the cell structure is difficult to observe.

The lack of structure allowed the identification of finely comminuted material discussed in Mason *et al*. (1994) and Pryor *et al*. (2013).

Aerenchyma

There is another form of parenchyma and that is aquatic and semi-aquatic plants. The oxygen for submerged plant organs such as the rhizomes of aquatic plants such as water lilies (Nymphaceae) and semi-aquatic monocot reeds and rushes such as *Typha and Juncus* is provided by the stomata in the leaves. However, aerenchyma in the rhizome and leaves provides both buoyancy for floating plant parts and starch storage. Aerenchyma is composed of chains of parenchymous tissue that allow air spaces between and is common in aquatic and semi-aquatic plants (Hather, 2000). There are two types of aerenchyma: Type one is chain-like parenchyma that creates air spaces and Type two is isodiametric parenchyma cells that surround large air spaces (Figure 3.11) (Hather, 2000).

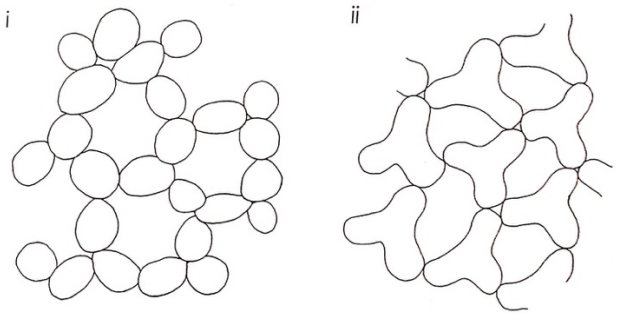


Figure 3.11: (i): Type one aerenchyma made of parenchyma cells in a chain-like formation creating air spaces; (ii) Type two aerenchyma made of isodiametric cells surrounding large air spaces. (Image taken from Hather (2000: 36) by C. Larbey)

Figure 3.12 shows type two aerenchyma, with isodiametric cells from a water lily rhizome.

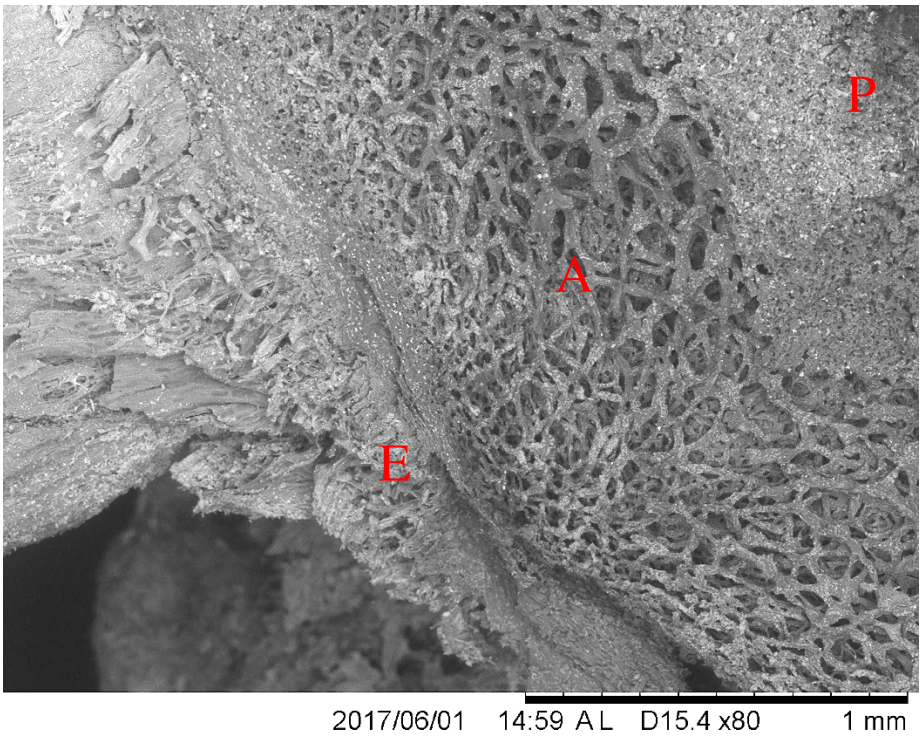


Figure 3.12: Type two isodiametric aerenchyma cells from *Nymphaea nauchali* (water lily) from the Klasies River modern reference collection. (Micrograph: C. Larbey)

There are other structures found within parenchyma that are characteristic of starchy plant tissue:

Secretory Cavities

All plants secrete substances, such as secondary metabolites (SM), in a large number of specialised forms, often unique to the species (Freeland and Janzen, 1974), with an estimated 200,000 compounds (Wink, 2010). Among these SMs are some of the most toxic compounds known, including alkaloids, cyanogenic glycosides, phenyl-propanoids, saponins, cardiac glycosides and terpenoids. Manioc (*Manihot esculenta*) contains cyanogenic glycosides, which are what make it so toxic, with death or severe deformity the result of incorrect or insufficient processing (Jones, 1998).

The primary metabolism governs the basic physiological processes, such as growing and reproduction through proteins, carbohydrates and amino acids. The secondary metabolism is essential for communicating with other organisms either to attract, as in the case of pollinators, or deter against herbivores or pathogens (Wink, 2010). These SMs are stored in secretory cavities (Figure 3.13) and latex ducts, the latter often near the surface (Hather, 2000). Their contents can also be varied apart from toxic chemical compounds and sometimes contain plant waste products or oils that may offer the plant's underground storage organ protection in the case of wild fire (Hather, 2000). SMs can also be metabolically recycled (Wink, 2010).

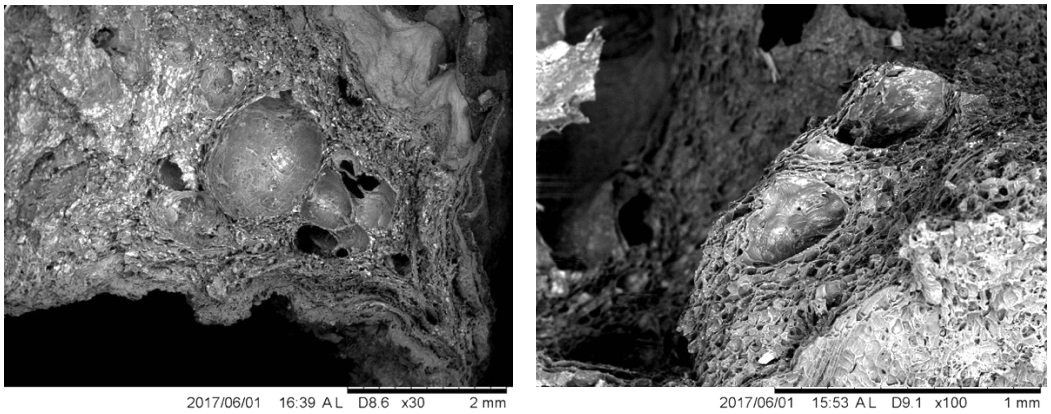


Figure 3.13: Secretory cavities: (Left) from *Rhoicissus digitata* a large (grapefruit-sized) tuber that holds a lot of water with a large secretory cavity over 1mm in diameter; (Right) *Zantesceschia aethiopica* (arum lily) bulb secretory cavities, comparatively large at over 0.5mm in diameter. Both samples from Klasies River modern reference collection. (Micrographs -lightened +17% - : C. Larbey)

Calcium oxalate and calcium carbonate crystals (phytoliths)

Calcium oxalate crystals are useful indicators of the presence of starch plants, particularly if surrounded by fused starch. Formed in idioblast cells within parenchyma, they are very specific to the plant, not be confused with post-depositional wood ash crystals from hearth contexts (Mentzer, 2016, Pers. Comm.). It is not known why the plant produces these crystals but there are two possible reasons. The first is that they are a form of herbivory defence to discourage animals from eating them and the second is that they are a by-product of the plant's metabolic process and a way for the plant to dispose of oxalic acid (Franceschi and Horner, 1980).

Calcium oxalate crystals can take the form of raphide, needle crystals, often in bundles, druse crystals, which are prismatic crystals (Hather, 2000) and sometimes amorphous-shaped crystals as in Figure 3.14. Calcium oxalate crystals are toxic and, if not fatal, may cause severe discomfort. These crystals have been considered to be part of a plant's defence mechanism but research has indicated other explanations: synthesis of oxalic acid may help the plant to maintain ionic equilibrium or that plants metabolise oxalate very slowly and these crystals may be a means of removing oxalate (Franceschi and Horner, 1980).

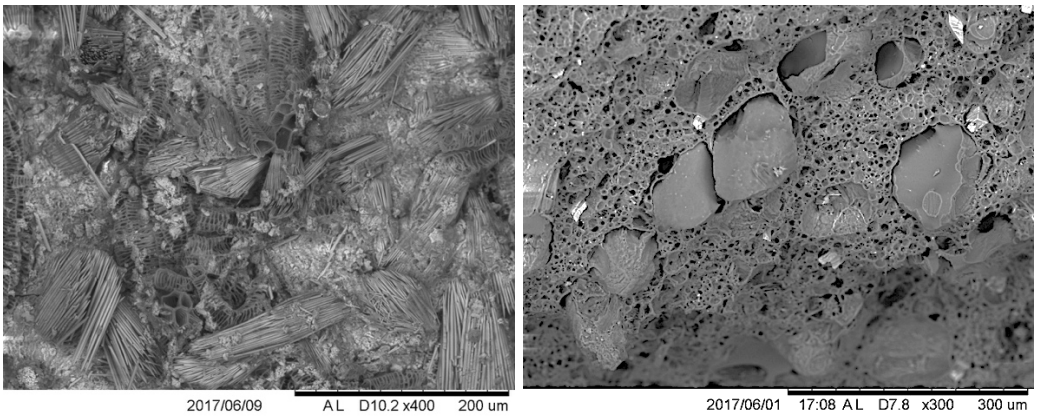


Figure 3.14: Calcium oxalate crystals: (Left) *Trachyandra ciliata* rhizome; called Cape Spinach, only the leaves are eaten unsurprisingly because the level of calcium oxalate raphide crystal bundles in the rhizome would be sufficient to cause stomach problems; (Right) *Watsonia pillansia,* clear view of calcium oxalate crystals forming and formed in the idioblast cells. Both from modern reference collection Klasies River. (Micrographs: C. Larbey)

Styloid crystals are calcium carbonate crystals like raphides but are larger and appear to form within vessels and are common to the Iridaceae and Liliaceae families (Hather, 2000).

Reproductive Characteristics

Fragmented parenchyma could have come from any part of an underground storage organ, each of which has its own growing habits and methods of reproduction and defence. Understanding these habits and the diagnostic morphological characteristics that might be preserved is helpful. Corms, for example, will only last for one year and create new 'daughter' corms underground for the next growing season. The *Watsonia* sp. corm in Figure 3.15 (right) shows

the withered corm from the previous year, with the diagram (Figure 3.15 left) showing the new daughter corms. Features of this process, such as a detachment scar, may be visible in the archaeological record.

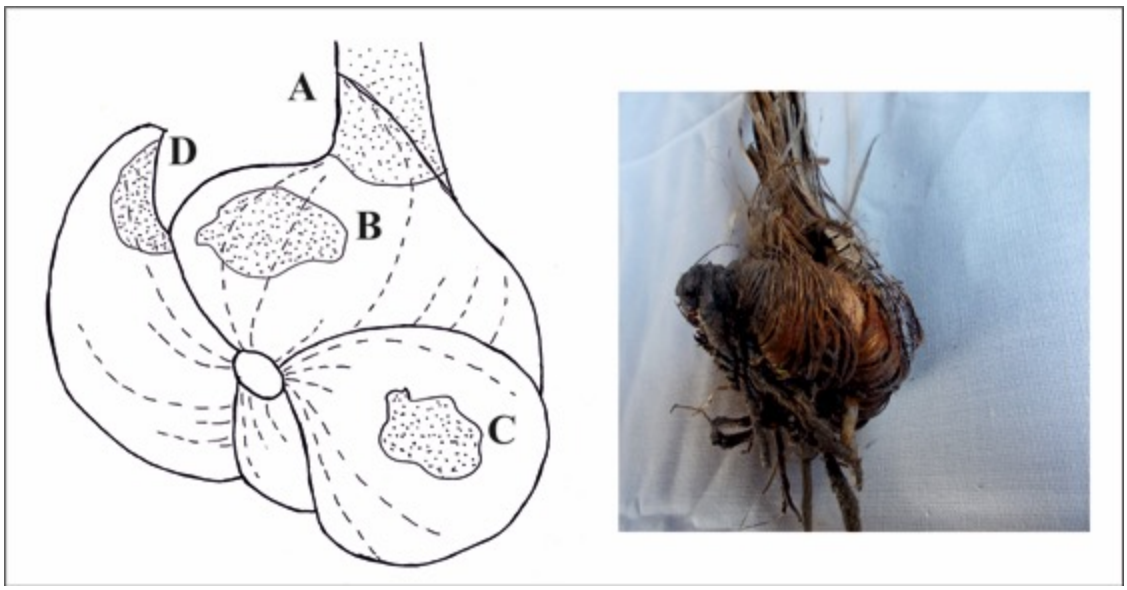


Figure 3.15: *Watsonia* sp. corm illustrated from cleaned corm pictured on the right. A: Distal end may show constriction of vascular tissues; B: epidermal fragment may have cortex and vascular tissue; C: parenchyma may have no vascular tissue or features; D: 'daughter' fragments from corms may be visible. Corm from the modern Klasies River reference collection. (Illustration after Hather (2000: 72) and photo by C. Larbey)

Terminal buds (the distal end of the tuber), and detachment scars, for example where the rhizome tuber has been attached to the parent plant outlined in red in Figure 3.16 (left), will distinguish tubers and rhizome tubers from bulbs (Hather, 1993; Hather, 2000).

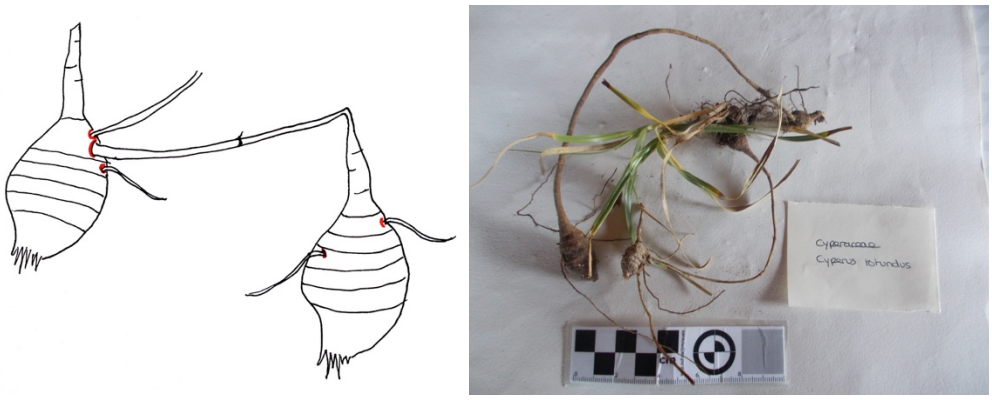


Figure 3.16: *Cyperus* rhizome tubers: (Left) diagram of reproduction and potential detachment scar areas marked in red; (Right) *Cyperus* rhizome tubers collected from the modern reference collection from Klasies River. (Illustration and photo: C. Larbey)

Cyperus sp. tubers from sedge grasses (Cyperaceae) have been found in many archaeological contexts, not just in Africa but in many of the archaeological contexts around the world. Growing on the edge of fresh water, they are a source of both bedding and food as seen in the MSA layers at Sibudu (Sievers, 2006; Sievers and Muthama Muasya, 2011; Wadley *et al.*, 2011). Cyperaceae detachment scars can be quite distinctive in the archaeological record.

3.5.3 Propagules: Seeds and Fruit

The characteristics most likely to survive charring in seeds are the seed testa and the hilum but also the embryo and endosperm. The seed size and shape, together with the nature of the seed testa, are the key characteristics for diagnosis (Figure 3.17), although the size may be distorted in the burning. (Pearsall, 2015).

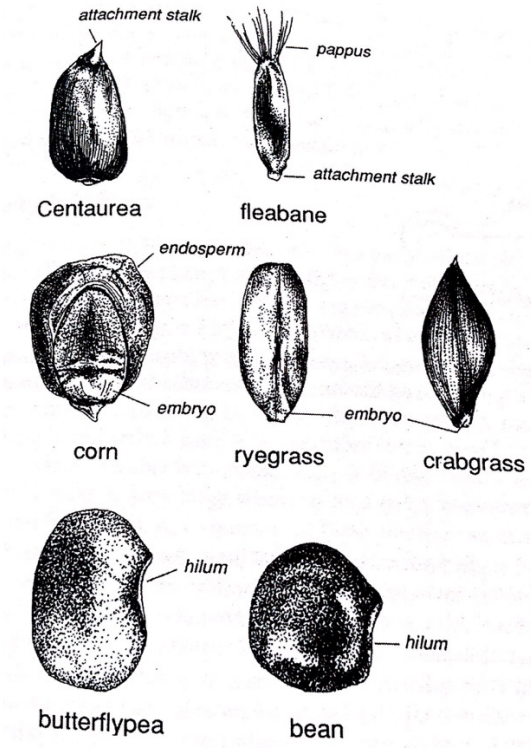


Figure 3.17:Angiosperm seeds illustrating identifying characteristics. (Image adapted from Pearsall 2015: 119)

Nut shells, legumes, fruit pips, stones and cupules could also be identified from charred assemblages.

Parenchyma, seeds and fruits from archaeological contexts are generally the waste by-products of food preparation that are either discarded or accidentally fall into the fire (Hillman, 1989; Mason *et al*., 1994). These waste fragments are then charred but not burned to ash because either they were at the edge of the fire, where the temperature is lower, or they were in oxygen-reduced conditions in the middle of the fire, where it is hotter (Hather 2000). As will be shown below, understanding this context is important when designing the sampling strategy of any hearth.

3.6 Tools for Plant Gathering and Processing

Artefacts directly associated with plant gathering, such as digging sticks that are usually made of wood, are generally considered unlikely to have been preserved in the archaeological record. However, desiccated digging sticks have been recovered from Border Cave, KwaZulu Natal, South Africa, dated to 39 kya (d'Errico *et al*., 2012). Border Cave has particularly dry conditions that have allowed exceptional preservation of wood remains through desiccation (Grün *et al*., 2003). The wood is identified as white berry bush (*Flueggea virosa* Roxb. Ex Willd. Voight subsp. *virosa*) and is typical of the digging sticks made by modern San (d'Errico *et al*., 2012). The similarity with San material culture is not unique. Ethnographic accounts report sticks for digging roots and tubers as part of an everyday tool kit for the Hadza, Tanzania (Marlowe and Berbesque, 2009; Vincent, 1985), the Kalahari San, South Africa (Steyn, 1984) and among Aborigine women in Australia (Bliege Bird and Bird, 2008). In Europe, evidence for digging sticks starts in the Lower Palaeolithic in Aranbaltza III, Spain. Here a digging stick, made of yew (*Taxus baccata*), and preserved by desiccation, dates to 171 kya (Rios-Garaizar *et al.,* 2018). A further digging stick from Grotta Paglicci Italy dates to 32 kya and appears to have preserved partially by charring and partially by desiccation in a dry part of the cave (Marriotti Lippi *et al.,* 2015). By the Mesolithic and Early Neolithic, digging sticks and digging stick weights become widespread across the world, with extensive evidence from the Central Sudan and Sahara (Fernández *et al.,* 2003, Fuller and Rowlands, 2011, Haaland, R., 2006).

In her paper on tuber consumption among modern Hadza communities, Vincent cites eight references dated from the 1960s and 1970s for archaeological digging stick use from across Africa and Europe from the LSA to the Viking period (Vincent, 1985). More importantly, digging sticks and associated digging stick weights from the LSA in South Africa are often not reported. Binneman reported the finding of a complete desiccated digging stick with geophyte remains from Augussie Shelter in the Eastern Cape, South Africa; there is no associated dating evidence (Binneman, 1994). His paper cites personal knowledge of digging sticks, often associated with plant remains or digging weights from other renowned LSA sites in South Africa but is not specific. Strathalan Cave, NE Cape had produced two complete and one broken digging stick, associated with a bored stone, dated to 2.5 kya. In the Kouga Mountains, 30 km NW of Kareedouw, a broken digging stick was dated to 4,490±60 ky. Others were identified at Collingham Shelter in Thukela Basin and in Diepkloof Shelter, SW Cape (Binneman, 1994). It is possible that in the excavations for MSA artefacts, for which most of these sites are famous, this evidence became marginal or may have been missed altogether.

Nic Eoin also points out in her paper that the assumptions and associations of geophyte processing with grindstones and adzes in early contexts are not conclusive and argues that the grinding of small grass seeds may have commenced earlier than assumed (Nic Eoin, 2016). Studies often only "mentioned in passing" these plant processing tools (Nic Eoin, 2016: 37). However, much of the evidence of grindstone use appears to have been dependent upon starch granule analysis. Given the critical assessment in the previous chapter, then it is not that surprising that grass starch granules are found on grindstones. Unless they have been removed carefully from the deposit, it is possible that they have been contaminated with airborne starch granules from the Poaceae family. The reassessment of artefacts in museum catalogues, as in D'Errico *et al*.'s research, appears to demonstrate that plant processing tools are now being considered in a more important light and that there may be more artefactual evidence connected with plant diets than previously thought (d'Errico *et al*., 2012).

There is worldwide archaeological evidence for the use of grindstones and stones used for grinding (grinders) (see Table 3.1) by ~30 kya, with evidence from:

Europe coming from Bilancino II, Italy, Pavlov VI, Czech Republic and Kostenki, Russia with grinders in deposits dates to around 30 kya (Revedin *et al.,* 2010); a grindstone from Haua Fteah Cave, Borneo, 31 kya (Barton *et al.,* 2018); grindstones from Cuddie Springs Australia, 30 kya; and grindstones from Africa dated to 30 kya have been found at Highlands Rockshelter, South Africa (Deacon 1976), but with a significant increase across Central Sudan and the Sahara by the Mesolithic/Early Neolithic (Fuller and Rowlands, 2011).

Table 3.1: Selected example of archaeological evidence for grindstones

Location	Date (kya)	Tool	Reference
Ohalo II, Israel	23	Grindstone*	Kislev *et al.,* 1992, Weiss *et al.,* 2004, 2008, Piperno *et al.,* 2004
Highlands Rockshelter, South Africa	30	Grindstone	Deacon, 1976
Bilancino II, Italy, Kostenki 16, Russia, Pavlov VI, Czech Rep.	30	Grinding Stones*	Revedin *et al.,* 2010
Cuddie Springs, Australia	30	Grindstone	Fullagar and Field, 1997
Haua Fteah Cave, Borneo	31	Grindstone*	Barton *et al.,* 2018
Atbara region, Sudan	10+	Grindstone	Fernández, *et al.,* 2003, Haaland, 2006
Early Neolithic sites, Sahara	7+	Grinders	Fuller and Rowlands, 2011
Daihai Lake, China	7	Grindstone	Liu *et al.,* 2014

*Use of grindstone determined by starch granule micro-fossil method

Grindstones found at MSA sites along the Cape coast are often associated with ochre and have been interpreted as ochre grindstones, rather than for plant use (Henshilwood *et al.,* 2011). Grindstones found in the Howiesons Poort levels at Klasies River are awaiting analysis.

3.7 Conclusion

This chapter has reviewed the processes of preservation and the archaeobotanical methods that may be used to look at the early human starch diet. Microfossils, whilst they have been used to reconstruct diet, have their limitations. Pollen is not a highly targeted indicator of starch plants, neither would its recovery and identification be regarded as evidence for a starchy plant diet. If there was evidence of grass seed consumption, phytoliths would be a very interesting

research method but roots and tubers do not, in general, contain phytoliths, so this method alone would exclude a key starch source. The study of starch granules as a method has still the authenticity and taphonomic issues to overcome, which could potentially dominate the research. Isotopes and plant waxes also would not provide any focussed data on cooked starchy plants. None of the methods described offers 100% coverage of early modern human plant starch consumption but the most promising method for this research is charred macro-fossils and, the latter is reviewed in Chapter 5 on Research Design, the following chapter will review current research on charred starch plant tissues.

Chapter 4

Archaeobotanical Evidence for Hunter-Gatherer Starch Consumption

4.1 Introduction

The focus of this chapter is to review existing research and evidence for starch plant diet of hunter-gatherers prior to the advent of agriculture in the late Pleistocene (Middle Palaeolithic/Stone Age and Upper Palaeolithic/Later Stone Age) across key regions of the World.

Analysis of readily recoverable artefacts such as stone tools and vertebrate remains has enabled the reconstruction of hunter-gatherer diets and suggested a clear narrative on the acquisition of meat, hunting and scavenging and even coastal foraging for fish and shellfish. But given the importance of plants to human life, this aspect of early hunter-gatherer diets has been under-researched, until recently.

Plant remains are less well preserved in the archaeological record and, at greater time depths, can be challenging and time consuming to recover. Recently, the tool kit available to archaeobotanists has been developed significantly. New methods have helped to recover more plant remains from different and older contexts. This is enabling archaeologists to identify human transitions based on plant diets other than agriculture and to redress the imbalance in the questions around earlier hunter-gatherer diets. This chapter reviews the methods and research for hunter-gatherer plant diets and some of the hypotheses developed that have reshaped thinking around the human diet.

During the last million years, the ability to control fire and cook food has been generally accepted as one of the key turning points in human evolution; humans are the only species that cook food (Wrangham *et al*., 1999b). Cooking would have significantly improved the digestibility of meat and particularly carbohydrates, as well as improving palatability (Carmody *et al*., 2011; Carmody

and Wrangham, 2009; Groopman *et al*., 2015; Hardy *et al*., 2015). Thermal treatment of carbohydrates, as discussed in Chapter 2, improves the energy availability from cooked starches (Butterworth *et al*., 2011). There are strong arguments made for the adaptive role played by cooking in the evolution and biological adaptations made within the *Homo* lineage (Wrangham, 2017) and it is argued that only with cooked food was the accelerated a number of morphological evolutions in the *Homo* lineage (Hardy *et al*., 2015). There are a number of arguments that counter this hypothesis based on the existence of large-brained *Homo erectus* during a period when there is little or no evidence of controlled fire (Gowlett, 2016).

Humans (*Homo sapiens*) had emerged in Africa by at least MIS 6 (~200 kya) (Mirazón Lahr and Foley, 2016). It is not known when fully anatomically modern humans (AMH) appeared. A recent full review of the human fossils from Klasies River, South Africa discovered that these remains, originally thought to be modern human, still retain ancestral characteristics (Grine *et al*., 2017). The earliest humans may have been in North Africa as early as 315 kya (Hublin *et al*., 2017). The debate about the morphology and chronology of *Homo sapiens* only affects this research a little. The genetic research suggests that the starch digestion genes duplication originates in *Homo sapiens* 300 kya (Inchley *et al*., 2016) and the current evidence from Jebel Irhoud (Hublin *et al*., 2017) falls within this chronological framework.

It is difficult to place a chronological bracket around the hunter-gatherer period, which ultimately appears to be terminated with the advent of agriculture and sedentism. Even then it is not completely clear that foraging does not continue to provide an important contribution to the agricultural economy. This late hunter-gatherer period is variously named the Mesolithic, Epi-Palaeolithic and Later Stone Age (but with regional variations such as Pre-Clovis or Early Archaic in North America and Canada and Incipient Jomon in Japan). The breadth of diet discovered from late hunter-gatherer sites gave rise to the 'broad spectrum hypothesis'. This hypothesis argued that dietary breadth was a pre-adaptation to agriculture (Flannery, 1969). This theory has been rejected for some time and the

following body of evidence, by region, is evidence of the breadth of plant foods used by hunter-gatherers.

This review, therefore, is divided by regions of the world because of the great variation in evidence between latitudes and the nature of the hunter-gatherer period by region. As far as possible, the research reviewed here will focus on the earliest human evidence available. Only when there is little evidence or when there is evidence that points to a knowledge of plants or processes that must have existed before the period in question is later evidence used.

The chapter will start with a summary of the methods being used to recover botanical remains from archaeological contexts and highlight some of the recent advances in methods. It will move onto the research and discussion around the diet of early hominin species such as Australopithecus and *Homo* species, such as *Homo ergaster/erectus*. Diet reconstruction has generally been based on theories that might account for the skeletal and dental morphological changes in early hominins (Hardy and Kubiak-Martens, 2016). Whilst there is no plant evidence from this early period, proxies such as carbon C_3 and C_4 stable isotope analyses, dental microwear and animal models suggest that the later species of Australopithecus ate roots and tubers.

Ethnographic, ethnobotanical and primatology research and evidence also contribute, although such evidence is mainly cited as appropriate in the text of the main body of this thesis.

4.2 Primate Starch Consumption

A number of scholars have argued that early hominins ate hard and brittle root and tubers and seeds, possibly as fall-back foods. Fallback foods are typically low nutrient or difficult to access foods that are relied upon when other foods are scarce (Laden and Wrangham, 2005). Certainly non-human primates have adapted to ecological niches in different ways; although most chimpanzees, bonobos and gorillas prefer ripe tree fruits, unlike gorillas and orangutans, they will target nutrient-rich plants that require behavioural adaptations to access them. Examples

are hard-shelled nuts, palm pith pounded to produce an edible pulp and stones and digging sticks used to dig up roots and tubers (Haslam, 2016). Conversely, gorillas have made morphological adaptations, teeth, gut and size, to allow them to consume abundant but low nutrient foods (Haslam, 2006). The starch diets of great apes have thus been useful in building comparative models for the diet of early hominins (Macho, 2014). Human evolutionary hypotheses have been built based on models using ecological, dental micro-wear morphology and isotopic parallels with animals such as Chacma baboons, bush pigs and African mole rats, all of which are large consumers of roots and tubers (Dominy *et al*., 2008; Sayers and Lovejoy, 2014; Yeakel *et al*., 2007).

All the great apes have been observed eating roots and tubers, except orangutans, whose diet consists largely of fruit but includes shoots, leaves, seeds and bark (Conklin-Brittain *et al*., 2006). Chachma (*Therpithecus gelada*), Mountain (*Papio ursinus*) and Hamadryas (*Papio hamadryas*) baboons (Johnson *et al*., 2013; Whiten *et al*., 1987), chimpanzees (*Pan troglodytes*) (Hernandez-Aguilar *et al*., 2007), gorillas (*Gorilla gorilla gorilla*) (Blake *et al*., 1995; Fay *et al*., 1989) and Capuchin monkeys (*Sapajus* spp. and *Cebus* spp.) have also been observed digging for and consuming roots and tubers in the wild (Falotico *et al*., 2017).

Roots, corms and bulbs account for between 23%-68.8% of the diet of both Chacma and Hamadryas Mountain Baboons (Byrne *et al*., 1993; Codron *et al*., 2006; Johnson *et al*., 2013; Macho, 2014; Whiten *et al*., 1987). These authors observed baboon consumption of bulbs, corms and rhizomes from taxa such as *Oxalis* sp., *Watsonia* sp. and *Cyperus* sp. These species are also consumed by hunter-gatherers, with both ethnographic accounts and archaeological plant remains described below.

4) Western lowland gorillas (*Gorilla gorilla gorilla*) from regions of the Democratic Republic of Congo and the Central African Republic, have also adapted behaviours. Here they have adapted to the wet season, not by moving to islands of dry land but by remaining in the forest swamps and exploiting new food sources. The sources of starchy plant foods both in and around these swamps are abundant during the wet season, including *Lasiomorpha*

senegalensis, *Cyperus latifolius* and *Raphia* sp., all swamp habit monocot species (Blake *et al*., 1995; Fay *et al*., 1989). The other plant foods they consume during these periods include members of the Zingiberaceae (ginger) family and Marantaceae (arrowroot) family, both of which are monocot families, and all of which bear starchy rhizomes. These swamp gorillas also eat the starchy pith and fleshy leaf bases of monocots such as *Pandanus candelabrum* and the fruits of *Afromomum* augustifolium. The gorillas from various forest swamps in West Africa have been observed standing feeding for some hours in water, demonstrating an important adaptation to environment to access starchy foods (Figure 4.1).

Figure 4.1: Western lowland swamp gorilla from Northern Central Congo eating semi-aquatic tubers. (Image: Rebrn.com)

Chimpanzees (*pan troglodytes*) occupy a broader range of habitats than most other primates, living in lowlands, montane forest, savanna and woodlands. Whilst they hunt and fish for termites, animal protein is considered to form only 5-10% of their otherwise plant diet. (Haslam, 2016)

Savanna chimpanzees have been recorded using digging sticks, or in one case a cow humerus, to dig for various species' tubers, including Fabaceae species, in Ugalla, Tanzania (Hernandez-Aguilar *et al*., 2007). It has been noted that

technology-using non-human primates preferentially target starchy plant foods, including chimpanzees, bonobos and baboons (Haslam, 2016).

Meanwhile, in Brazil, wild capuchin monkeys have been observed using stone tools to dig for tubers of fanweed (*Thiloa glaucocarpa*) tubers and sweetwood (*Ocotea* sp.) roots. This research assessed the possibility of these being fallback foods and, therefore, the use of tools to dig them up might be a function of the "necessity hypothesis". However, there was a positive correlation between plant food availability and stone tool use which suggests that the fanweed tubers were staples and not fallbacks (Falotico *et al*., 2017).

What is interesting to note from the starch diet of non-human primates is that they are divided between those that have adapted behaviourally, predominantly chimps, bonobos and baboons, and those that have adapted morphologically, mostly gorillas and orangutans. Among the behaviourally-adapted, non-human primates, tool-use has evolved, not to reach more preferred foods such as fruit, but to subsist on high quality foods, in different ecologies, year round. This behaviour is supported by niche construction theory and definitely has parallels with the starch plant diet of early hominins.

4.3 Early Hominins: arguments for starchy plant diet

Climate change in the Pliocene (4.4 mya) reduced forested areas in Ethiopia, Africa creating a mosaic of savanna, wetlands and forest (White *et al*., 2009). This climate and consequent environment change is held to be the key driver in diet and morphological changes amongst early hominids. Isotope studies of various vertebrate taxa with varying taxonomic habit indices (THI) have enabled the recreation of this mosaic landscape (White *et al*., 2009). There is little plant evidence from this time, except the discovery of *in situ* silicified plants from the margin of a palaeo-lake at Olduvai Gorge, Tanzania. These plant fossils attest to the availability of *Cyperus* sp. (sedge) tubers and a variety of roots and rhizomes ~1.7-1.8 million years ago (Bamford, 2012; Bamford *et al*., 2008).

Diet has been at the centre of the discussions about how early hominids and archaic hominins fuelled evolutionary morphological changes (Hardy *et al*., 2015). The key changes include: changes in tooth morphology (Cerling *et al*., 2011; Ungar and Sponheimer, 2011); a reduced gut size, which was achieved 1.8 million years ago (mya) ; and encephalisation, which accelerated from around 800 kya (Aiello and Wheeler, 1995; Hardy *et al*., 2015). Whilst it has been argued that the transition from a fibrous plant diet to an omnivorous diet that included increased amounts of meat (Aiello and Key, 2002; Milton, 1999; Milton, 2003) fuelled these changes, others have argued that plant carbohydrates as well as meat were essential to meet the increased metabolic demands of an enlarged brain (Conklin-Brittain *et al*., 2002; Hardy *et al*., 2015; Wrangham, 2009).

Although it is uncertain which species of Australopithecus might be the direct ancestor of the genus *Homo*, the archaeological narrative on the human carbohydrate diet commences with how the diet of later Australopithecus species such as *A. africanus* and *Paranthropus boisei* changed to include more meat and increased amounts of starchy roots and tubers and grass seeds (Dominy *et al*., 2008; Lee-Thorp *et al*., 1994; Peters and Vogel, 2005; Sponheimer and Lee-Thorp, 2015; Sponheimer *et al*., 2005a; Sponheimer *et al*., 2005b; Sponheimer *et al*., 2013; van der Merwe *et al*., 2003). This dietary shift suggests a greater flexibility in their ability to find higher calorie, year-round food sources in different ecologies as they moved away from the forest into a mosaic environment of savanna and wetlands: an adaptive behaviour that would be critical for *Homo* (Cerling *et al*., 2011; Dominy, 2012; Dominy *et al*., 2008; Laden and Wrangham, 2005; Lee-Thorp *et al*., 2012; Macho, 2014; Schoeninger, 2014; Sponheimer and Lee-Thorp, 1999;Sponheimer and Lee-Thorp, 2015; Ungar and Sponheimer, 2011; van der Merwe *et al*., 2003; Wrangham *et al*., 1999b).

The *Homo* lineage saw major developments in brain size and morphology, which included an increase in limb length, the overall size of females, and even in changes in reproduction, developments that would have required not just a high quality diet but a significantly greater energy requirement (Aiello and Key, 2002; Hardy *et al*., 2015; Leonard and Robertson, 1997; Steudel-Numbers, 2006). The early *Homo* species, *H. rudolfensis* and *H. habilis* appear to have had a flexible

subsistence strategy, allowing them to adapt to the different ecosystems emerging in Africa at the end of the Pliocene (Ungar *et al*., 2006a). *Homo erectus/ergaster*, however, underwent significant morphological changes that would have required a much greater energy input (Hardy *et al*., 2015). After 800 kya there was an acceleration in the rate of increase in brain size (Lee and Wolpoff, 2009), in larger bodies, particularly females (Aiello and Key, 2002; Leonard and Robertson, 1997; Steudel-Numbers, 2006) and a number of adaptations to enable them to run (Bramble and Lieberman, 2004). In *Homo erectus* there were also adaptions to the pregnancy, birth and weaning of large brained infants. The mother gives birth to larger babies at the point at which the baby starts to consume the energy the mother needs for herself. So babies are born before they are capable of being independent (altricial) but with a layer of fat that provides a nutritional buffer for the infant prior to the commencement of breastfeeding and at weaning (Cunnane and Crawford, 2003; Herrera, 2000; Kuzawa, 1998).

Wrangham has argued that this significant increase in energy demand could only have been met by cooking food (Wrangham, 2009). Cooking would essentially pre-digest the food and thereby reduce the calories required to digest the food and cooking would increase the calorific content of plant foods by turning the starches in sugars (Carmody *et al*., 2011).

4.4 The Control of Fire and Cooking

The importance of increased quantities of meat and the inclusion of starchy plant foods in the diet, as opposed to highly fibrous leaves and stems, have been prominent themes in the evolution of human diet (Aiello and Wheeler, 1995; Dominguez-Rodrigo and Rayne Pickering, 2003). One of the most apparently significant shifts for the evolution of the *Homo* genus was the ability to cook food. Cooking would have relied upon the control and manipulation of fire, the evidence for which is widely debated. It has been argued that the control of fire and cooking developed around 1.8 million years ago when the larger brained *H. erectus* begins to emerge from the fossil record (Aiello and Key, 2002; Gao *et al*., 2017; Leonard *et al*., 2003; Pontzer *et al*., 2011; Steudel-Numbers, 2006; Ungar *et al*., 2006a; Ungar *et al*., 2006b; Wrangham *et al*., 1999b). Yet early evidence that

distinguishes wild fire from anthropogenically controlled fire is limited (Bellomo, 1994; Brain and Sillen, 1988; Gowlett *et al*., 1981). Among the earliest putative evidence for cooking are the burned bones and ashed plant remains from Wonderwerk Cave, Northern Cape, South Africa that date to 1 million years ago (Berna *et al*., 2012). Further cooking has been attested 800 kya at Gesher Benot Ya'aqov, Israel (Alperson-Afil, 2008; Alperson-Afil and Goren-Inbar, 2010; Hardy *et al*., 2015; Melamed *et al*., 2016) with the discovery of charred plant and animal remains, associated with lithics. Evidence for repeated use of hearths is found at Qesem Cave, Israel, 300-400 kya suggesting a deep history of fire control, use and cooking (Barkai *et al*., 2017; Shahack-Gross *et al*., 2014).

The dietary significance of cooking in human evolution is that it significantly increases the energy yielding potential and glycaemic index of foods (Hardy *et al*., 2015), as well as their digestibility and palatability. The cooking of plant foods such as roots and tubers essentially pre-digests them, turning them into preformed glucose, which allows greater energy to be derived from similar quantities of foraged food (Carmody *et al*., 2016; Carmody and Wrangham, 2009; Wrangham and Carmody, 2010). Roasting would also have neutralized secondary metabolites, thus bringing a wider range of starchy plants into the range of potential food sources (Carmody *et al*., 2011; Schnorr *et al*., 2016a). Protein alone would not have met the increased energy demands (Speth and Spielmann, 1983). Ketones from fat oxidation would only provide around 80% of the brain's metabolic needs (Hardy *et al*., 2015) and both lipids and glucose would have been required to create fat babies (Butte, 2000; Cunnane and Crawford, 2003). The increased energy availability from cooked carbohydrates in the diet had an important impact in meeting the increased metabolic demands of a larger brain, plus larger bodies and fat babies (Dunsworth *et al*., 2012; Hardy *et al*., 2015).

4.5 Neanderthals Ate Starchy Plants

Neanderthals are an archaic human species that, it is generally agreed, evolved from *Homo heidelbergensis* outside of Africa (Mellars, 1996; Stringer and Gamble, 1993). The Neanderthal and human lineages diverged ~ 650 kya (Green *et al*., 2008; Meyer *et al*., 2016; Prüfer *et al*., 2014b) but despite genetic

divergence and morphological differences, they co-existed and interbred (introgressed) with humans, leaving a small element of Neanderthal ancestry in the genomes of many modern, predominantly European, humans (Khrameeva *et al*., 2014; Reich *et al*., 2016). They inhabited Europe, Northern, Central and Southwest Asia (Figure 4.2), living in glacial conditions as far north as Altai, southern Siberia (not marked on map) (Dobrovolskaya and Tiunov, 2013), as far south in Europe as the Iberian Peninsula, in the Near East at Amud, Tabun and Kebara Caves in Israel (Lev *et al*., 2005; Rak *et al*., 1994; Salazar-García *et al*., 2013) and as far east as Shanidar Cave, Kurdistan, with their recently discovered Neanderthal fossils (Pomeroy *et al*., 2017). The geographical range of Neanderthals covered a variety of biomes and climates, suggesting dietary flexibility would have been necessary. And yet, their dietary narrative has been that of meat-eaters of the order of carnivores (Richards *et al*., 2000).

Figure 4.2: Range of Neanderthals from 300-30 kya – does not show all Neanderthal sites. (Image by courtesy of Creative Commons CC BY-SA3.0)

This dietary narrative has, until recently, been determined by analysis of the vertebrate remains and lithics from Neanderthals' sites; nitrogen stable isotope analysis of Neanderthal fossil remains (Richards *et al*., 2000); and dental microwear (Hardy, 2010). The hunting and scavenging patterns, spatial patterns of vertebrate remains, including preferred elements for consumption, and associated

lithics as weapons and for processing carcasses are defined in detail for Western European Neanderthal subsistence in Mellars' seminal '*The Neanderthal Legacy*' (Mellars, 1996). The nutritional demands of pregnancy and child-rearing are discussed and the solution suggested as male provisioning and food-sharing (Mellars, 1996: 361). It is interesting that no other form of subsistence or potential foraging is considered in this book.

Isotope analysis of Neanderthals from Vindija, Croatia showed that their diet consisted primarily of meat (Richards *et al*., 2000). The animals they were eating developed a north-south pattern, with large-bodied, open-habitat herbivores (horse, bison, rhino and elephant) preferred by northern Neanderthals, with a preference for medium-sized herbivores (red deer, ibex and chamois) in the regions of Spain and SW France, despite the presence of larger animals (Bar-Yosef, 2004; Conard and Prindiville, 2000; Dobrovolskaya and Tiunov, 2013; Weyrich *et al*., 2017). The issue with nitrogen isotopes is that they only track protein and do not discriminate for quantity, for example the difference between a diet of 50% protein and 100% protein is 0.5‰ (‰ = parts per million) (Ambrose *et al*., 2003; Kuhn and Stiner, 2006).

From more recent research it seems that Neanderthals were able to find a broad diet from the environments they inhabited throughout the seasons (Fa *et al*., 2016; Hardy, 2010; Salazar-García *et al*., 2013; Weyrich *et al*., 2017). From the results of DNA analysis of fossil dental calculus, it appears that the Neanderthals from Spy Cave, Belgium consumed more meat such as rhino and wild sheep (Weyrich *et al*., 2017), whereas, by comparison, it is suggested that the Neanderthals from El Sidrón, Spain consumed fungi, moss and pine nuts, suggestive of exploitation of a forest environment (Radini *et al*., 2016; Weyrich *et al*., 2017).

Through a mixture of methods, micro-fossil and chemical analysis of Neanderthal dental calculus (Hardy *et al*., 2012) concluded that they consumed plants with potential medicinal uses, such as camomile. It has been argued, however (Buck and Stringer, 2014), that eating the chyme (stomach contents) of herbivores that had grazed these plants may be a more likely route of entry into dental calculus. However, starch granules were also recovered from the four adult and one juvenile

Neanderthals from El Sidrón, Spain, which would support the DNA findings by Weyrich *et al*. (2017) discussed above.

In Gibraltar, Neanderthals appear to have foraged shallow coastal waters for molluscs and fish. They also ate deer, rabbit and birds and the carbonised remains of grass seeds, stone pine nuts and olives attest to regular plant elements in their diet (Barton *et al*., 1999; Fa *et al*., 2016; Gale and Carruthers, 2000; Stringer *et al*., 2008).

Archaeobotanical research at Kebara Cave, Israel, recovered a large assemblage of charred plant remains, which attests to a plant diet of sedge tubers (*Cyperus* sp.), reed rhizomes (*Phragmites australis*) and lily bulbs (Liliaceae), with 78.8% of the 3,313 remains coming from the legume family, including 25 species such as bitter vetch (*Vicia ervilia*) and peas (*Lathyrus sativus* and *Lathyrus annus*). These remains also evidenced the exploitation of arboreal resources, suggesting that Neanderthals consumed acorns (*Quercus ithaburensis* and *Q. caliprios*) and pistachios (*Pistachio atlantica*) (Bar-Yosef *et al*., 1992; Lev *et al*., 2005; Shipley and Kindscher, 2016). At Amud Cave, Israel, phytolith evidence also indicates that Neanderthals included palm greens, fruit and figs as part of their plant diet (Madella *et al*., 2002).

The evidence from starch granules extracted from Neanderthal dental calculus has suggested grass seed and root and tuber consumption (Henry *et al*., 2011; Henry *et al*., 2014; Power *et al*., 2018). These findings also include one water lily (*Nymphaea* sp.) starch grain in the fossil dental calculus of a Neanderthal from Spy Cave, Belgium (Henry *et al*., 2014). A recent study of phytoliths and starch granules from fossilized dental calculus from Neanderthal teeth took 28 samples from 22 individuals from five sites (90-30 kya). The results indicated that Neanderthals used plant foods as part of their subsistence strategy but concluded that processing requirements of plant foods are often a limited factor in their use. The study also suggests that being able to identify processing might reveal how humans were able to replace Neanderthals (Power *et al*. 2018: 37). Equally the study of microfossils from the dental calculus of the Neanderthals of Sima de las Palomas, Spain based their conclusions about plant diet on nine microfossils

(phytolith and starch granule), which were leafy matter, seed endosperm, grass seeds and possibly root or tuber in origin (Salazar-García *et al*., 2013).

There have been early arguments for a mixed and broad diet among Neanderthals (Hansen, 1991; Hardy, 2010; Pérez-Pérez *et al*., 2003) and whilst it appears that meat often dominated their diet, plant foods played an important role in supplying sufficient energy and starch (Gale and Carruthers, 2000; Lev *et al*., 2005; Madella *et al*., 2002; Weyrich *et al*., 2017). Equally important, these findings also support an ability to adapt their subsistence to changing climate and environment (Radini *et al*., 2016; Weyrich *et al*., 2017). The climate conditions outlined in Table 4.1 indicate how difficult it would have been to obtain plant foods at various times across Europe and Northern Asia. So the synthesis of the findings above must take into account the seasonal nature of Neanderthal plant foods.

Table 4.1: Outline of European climatic conditions during the period of Neanderthal occupation, adapted from Steegmann *et al*. (2002) and originally from Stringer and Gamble (1993)

Date (kya)	Climate	Conditions
250-180	Early Glacial	Temperate/cool. Mid-latitude forests fall back to a pattern of patchy woods and grasslands. Herd animals such as horse and red deer are established. Mean annual temperatures possibly 0° to -5°C with cool summer (July mean 15°C)
180-130	Full Glacial	Some mild intervals; generally continental shelves exposed; glaciers advance; non-forest flora prevails; human/animal refugia in protected areas. Mean annual temp -5°C to -15°C with July temperatures at only 5° to 11°C
130-115	Interglacial	Subtropical forests and fauna advance to mid-latitude. Continental shelves fully submerged
115-75	Early Glacial	Temperate/cool as before
75-30	Early Glacial	Cool to glacial conditions. As glaciers take up water, continental shelves emerge; northern latitude tree cover is reduced to sheltered areas. Central Europe is barren and arid "dustbowl" conditions produce loess soils. Est. mean annual temperature at 55 kya -7°C (11°C in July. By 40 kya fluctuating amelioration begins

It has been suggested that Neanderthals differ from humans in that it appears that the evidence for cooking their food is limited (Henry, 2017). However, this lack of evidence may be associated with lack of research in this field. Further

archaeobotanical research into Neanderthal hearths is needed. Dibble *et al*. (2017) discovered that evidence of Neanderthal fires is only found from warm periods, not cold ones, which has led to the hypothesis that, in some parts of Western Europe, Neanderthals may not have cooked their food. The findings point to prolonged periods (that coincide with cold periods) without fire but with evidence of occupation (Dibble *et al*., 2017; Sandgathe *et al*., 2011). Without doubt Neanderthals had the knowledge to make fire in some areas, but these discoveries question whether the use of fire was "not an essential part of Neanderthal behavior" (Sandgathe *et al*., 2011: 217). However, in the absence of wood to burn as fuel, which would be the case in extreme cold and arid environments, animal dung is a desirable fuel and plant remains could enter the fire through that route (Henry, 2017; Miller, 1996). As Henry points out, there is more research required to establish both fire use and whether plant remains have been cooked for food (Henry, 2017). This evidence provides a stark contrast to human sites of a similar period where hearths have produced evidence of starchy plant consumption, for example at Dolní Věstonice, Czech Republic (Pryor *et al*., 2013). Evidence of gelatinised starch granules recovered from fossilised dental calculus from the El Sidrón Neanderthals suggests that they ate cooked starch (Hardy *et al*. 2012: 620).

If Neanderthals did not cook food, and plant foods in particular, then a subsistence strategy that included raw plant foods, particularly in colder and higher latitudes, was significantly more risky than a diet of meat and fat because of the higher risk of plant toxicity in a seasonal landscape (Jones, 2009b).

How Neanderthals met their energy requirements if they ate their food raw is still under debate (Dibble *et al*., 2017; Henry, 2017). Steegman *et al*. discussed the potential for Neanderthals to have various biological adaptations that would allow them to tolerate cold conditions but these have not been proven (Steegmann *et al*., 2002). What is understood genetically is that Neanderthals underwent enrichment to the genes connected with their lipid catabolism (fat digestion), which would have offered protection against the cold in the glacial conditions outline in Table 4.1 (Khrameeva *et al*., 2014). A diet high in fat would have allowed them to offset the nitrogen toxicity potentially incurred from the consumption of large quantities of lean meat (Jones, 2009b; Speth and Spielmann, 1983). A parallel for this can be

seen in modern humans among circum-Arctic Inuit today, where a mutation in their fat catalysing gene CPT1A has helped them to tolerate both cold and a high fat diet (Clemente *et al*., 2014). In fact the Neanderthal lipid catalysing adaptive variants were passed on to European humans through introgression and brought to high frequency by positive selection, *i.e*. higher fat tolerance in the Neanderthal diet was passed on to European modern humans for whom it was also important in adapting to harsh cold environments in the North (Khrameeva *et al*., 2014). However, it appears that at least some Neanderthals consumed starch, particularly in the warmer Mediterranean climates of Iberia and Israel.

4.6 The Lack of Denisovan Evidence

Denisovans are another archaic human species, best known from the genetic analysis of the few fossils found in the Denisova, Southern Siberia. Denisovans are also are descended from *Homo heidelbergensis* and closely related to Neanderthals. Their geographic spread took them from Northern Asia to Southwest, Southeast Asia and East Asia, with the Han Chinese, Japanese and Dai people having a close genetic relationship with Denisovans (Huerta-Sánchez *et al*., 2014; Reich *et al*., 2010). Little is known about the Denisovan diet, although their ability to disperse into diverse regions from Siberia to Southeast Asia would suggest a dietary flexibility.

4.7 Humans – The evidence for the hunter-gatherer starch diet

The following evidence is divided by region around the world and discusses the oldest evidence of starch consumption in that region. It starts with the late hunter-gatherers immediately prior to the advent of agriculture in Southwest Asia. Discoveries from Upper Palaeolithic sites from this region such as Ohalo II, Israel have re-shaped archaeological thinking about the role of plant foods in the hunter-gatherer diet. But the regions include East and Southeast Asia, Australia, Americas, Europe and Africa. In each region, the author has researched the oldest possible evidence for starch consumption.

The emergence of sedentism and agriculture was a very gradual process. The 'Neolithic Revolution' (Childe, 1936) implied a suite of changes that occurred in a comparatively short space of time between 11-3 kya. These included moving from mobile lifestyles to living in settlements; having somewhere permanent to live and store 'things' they made, such as pottery in which to carry, cook and store food; and new stone tool technologies. They grew plants that by a process of selection became (in general) larger, grass grains became larger cereal grains, tubers such as yam and taro became larger. Similarly animals became domesticated and their favoured morphologies, size *etc* were selected for breeding (Barker, 2006). It is now understood that there was a convergent domestication of plants all over the world, with, as in the case of rice, multiple parallel domestications that followed a long period of human knowledge and use of these plants (Figure 4.3) (Fuller *et al*., 2014).

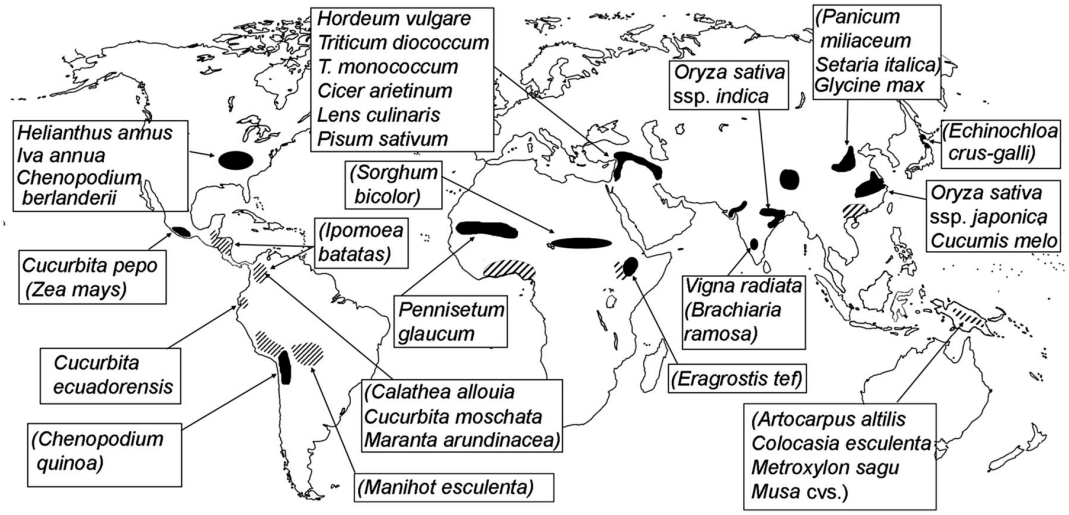


Figure 4.3: Map of centres of domestication : hatched areas = vegeculture; black = cereals and seeds. Image from Fuller *et al*. (2014: 6148)

The transition from hunting and gathering lifeways to agriculture had vastly differing chronologies across the world. Pottery is considered one of the signatures, alongside cereals, domesticated animals and evidence of settlements, of the appearance of the Neolithic in Europe and yet pottery for cooking and storage was developed and used by mobile foraging societies 20 kya in China (Wu *et al*., 2012). In Japan, pottery was an integral part of Jomon hunter-gatherer communities around 15 kya (Craig *et al*., 2013). And yet among the Jomon, plants

and animals were less farmed than 'supervised' (Bleed and Matsui, 2010) until the arrival of intensive rice farming, new pottery designs and new tools ~2.4 kya from Korea (Barker *et al*., 2006; Diamond and Bellwood, 2003; Higham, 2005). In southwest Asia, evidence of an Epi-Palaeolithic hunter-gatherer society, the Natufian culture (15-7.5 kya), combined stone tools that included sickles used for wild grass harvesting and large mortars and grinding stones (Barker, 2006; Diamond and Bellwood, 2003; Watkins, 2005). Recent evidence from Shubayqa 1 in northeastern Jordan has shown that early within the Natufian culture, this pre-agricultural society made the first known flat-bread using a combination of pre-domesticated wheat and tubers (Arranz-Otaegui *et al*., 2018a).

The late hunter-gatherer period immediately preceding the advent of agriculture is variously named the Upper and Epi-Palaeolithic (Asia), the Later Stone Age (Africa and Australia) and the Upper Palaeolithic and Mesolithic (Europe). In the Americas it is the Early Archaic, Pre-Clovis or Early Component and in Japan, the Incipient Jomon. Research from these periods has produced rich archaeobotanical evidence. The archaeobotanical findings from this period undoubtedly depict the hunter-gatherers' in-depth knowledge of plants and vegeculture, a diversity of diet and a preference for which that ultimately led to 'domestication'.

4.7.1 Southwest Asia

This region is best known for the origins of agriculture in a semi-circular area named the Fertile Crescent (Figure 4.4) (Breasted, 1916; Breasted and Robinson, 1914). Many of today's cereals such as wheat, barley and flax, and legumes such as chick peas and lentils were domesticated in this region, and were known as 'founder crops' (Barker, 2006). But the story of this region starts at the height of the last ice age. Twenty thousand years ago, the Last Glacial Maximum (LGM), meant that this region had a climate that was cold and dry. Plants adapted to this colder, dryer climate by producing more but smaller seeds (Bennett *et al*., 2012). Equally, underground storage organs were an adaptive response to the conservation of energy and water below ground but also a way of reproducing without relying on pollen, particularly in competitive conditions (Proches *et al*., 2006).

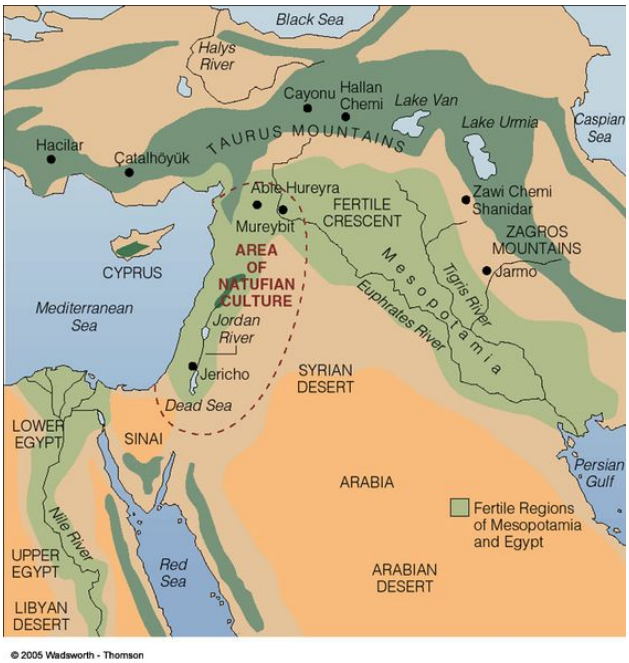


Figure 4.4: Map of Southwest Asia showing region of Natufian culture and selected early Neolithic sites. (Map: PB_Hausarbeiten)

These climate conditions would have turned much of the landscape in this region into steppe and grass seeds would have been available in the isolated woodland areas of the Zagros Mountains and Caspian Sea littorals to the East and the Mediterranean Sea littorals to the West. Roots and tubers would have been available from the steppe vegetation (Barker, 2006). Before the emergence of agriculture, however, the hunter-gatherers of this region adapted their mobility and diet to seasonal availability of game and plants (Barker, 2006; Hillman, 1996).

One of the key themes is that hunter-gatherers were consuming large quantities of grass seeds, in addition to other high energy starchy plants such as legumes, fruits, nuts and roots and tubers (Table 4.2). The roots and tubers came particularly from water-based species. The Kebaran foragers were small bands of highly mobile hunter-gatherers who moved through this region and are best understood from the extraordinary site of Ohalo II in Israel (Kislev *et al*. 1992; Nadel and Werker, 1999; Nadel *et al*., 2004; Nadel *et al*., 2015; Weiss *et al*., 2004).

Table 4.2: Sites of starchy plant macro-remain finds from late hunter-gatherer sites in Southwest Asia (representative only).

Southwest Asia	**Age (kya)**	**Period**	**Type of Plant Remain**	**Reference**
Ohalo II, Israel	23	Upper Pal.	Water logged grass seeds, pistachio nuts and fruits	(Kislev *et al*., 1992; Nadel and Werker, 1999; Weiss *et al*., 2004)
Wadi Jilat, Badia, Jordan	19.5 kya	Upper Pal.	Charred Chenopodiaceae and Cyperaceae seeds	(Colledge, 2013)
Öküzini Cave, Anatolia, Turkey	18.2-11.8	Epi-Pal.	Charred Fruit, nuts, tubers, roots bulbs	(Martinoli, 2004; Martinoli and Jacomet, 2004)
Wadi Kubbaniya, Egypt	20k-12	Epi-Pal.	Dried roots and tubers	(Hillman, 1989; Hillman *et al*., 1989b)
Shubayqa I, Jordan	14.6-11.5	Natufian	Charred tubers, rhizomes, stems, nutlets, grass seeds	(Arranz-Otaegui *et al*., 2018b)
Wadi Hammeh 27, Pella, Jordan	12 kya	Late Natufian	Charred seeds, and starchy plant parts	(Colledge, 2013)
Hayonim Cave, Western Galilee, Israel	12.3-12	Natufian	Charred wild barley, almonds and lupin seeds	(Hopf and Bar-Yosef, 1987)
Abu Hureyra Phase I, **Syria**	12.5	Epi-Pal.	Charred almonds, club-rush, wild wheats and ryes	(Hillman, 2000; Hillman *et al*., 1989a)

The site of Ohalo II was discovered when drought caused the water levels to drop in the Sea of Galilee, Israel. The site is dated to 23 kya and, being water-logged, provided a perfectly preserved hunter-gatherer campsite that included brush huts and plant food remains not normally preserved. The hunter-gatherers of Ohalo II foraged a wide variety of grass seeds that included the wild varieties of barley and emmer wheat. They exploited arboreal resources such as acorns, pistachio and wild olive that provided carbohydrates and fats and fruits such as wild figs and wild grapes (Kislev *et al*., 1992; Nadel *et al*., 2015; Weiss *et al*., 2004).

Within the same period, in Öküzini Cave, Anatolia, Turkey (18-12 kya) evidence of wild pears (*Pyrus* sp.), wild grapes (*Vitis sylvestris*) and rose (*Rosa*), and nuts such as wild almond (*Amydalus* sp.) and pistachio (*Pistachia* sp.) was found alongside parenchyma fragments of roots and tubers (Martinoli, 2004; Martinoli and Jacomet, 2004). Wadi Jilat in the Badia in eastern Jordan (19.5 kya) also showed evidence of high carbohydrate and fat rich plant exploitation with the

presence of Cyperaceae seeds and Chemopodiaceae, that indicate the exploitation of water and steppe environments (Arranz-Otaegui *et al*., 2016; Colledge, 2013).

In upper Egypt, at Wadi Kubbaniya, plant remains were recovered from hearths and human palaeo faeces dated to around 16-15 kya. The site near Aswan is ~3 km from the Nile on a series of dunes that, at the time and in the right season, would have overlooked a swampy floodplain with fish pools (Hillman, 1989). Here they exploited rhizomes and tubers from water-based plants such as several varieties of sedge grass (Cyperaceae), reeds (*Phragmites*), cattail (*Typha* sp.), bulrushes (*Schoenoplectus* sp.), waterlilies (Nymphaceae) and bistort (*Polygonum senegalense)* (Hillman, 1989; Hillman *et al*., 1989b). Hillman argues here for the first time that starchy plant foods were ground for weaning on the evidence of infant faecal matter found charred in a hearth (Hillman, 1989). These hunter-gatherers were also consuming grass seeds, particularly from the millet family, such as *Paspalidium germinatum*.

The Natufian culture was discovered and defined by Dorothy Garrod in the 1920s and 30s and describes the indigenous late hunter-gatherers in a region that starts with Syria in the north, incorporating Lebanon, Jordan and Israel as far as the Dead Sea in the South, bordered on the Western side by the Mediterranean (Figure 3.4). There are more than 86 sites attributed to this culture, with similar archaeobotanical profiles, hence the sites discussed here are only representative (Arranz-Otaegui *et al*., 2018b).

Indicative of early Natufian culture are the sites of Wadi Hammeh 27, Hayonim Cave, Shubayqa 1 and the Epi-Palaeolithic levels of Abu Hureyra 1. By around 13 kya, the climate had begun to improve as the Bølling-Allerød interstadial began to take effect (Arranz-Otaegui *et al*., 2016). In the warmer climate more fruits and nuts would have become available. These sites have in common large assemblages of plant foods including wild grasses that were the founder plant species for subsequent cereal crops. But they also have in common the use of other high energy plants: legumes such as peas (*Pisum* sp.), chick peas (*Cicer* sp.), broad beans (*Vicia faba*), bitter vetch (*Vicia ervilia* L.) and grass pea (*Lathyrus* sp.) and including roasted lupin seeds (*Lupinus albus* L.) at Hayonim Cave (Hopf and Bar-

Yosef, 1987) and fruits and nuts such as pistachios (*Pistachia atlantica*), and almonds (*Amygdalus* sp.). At Shubayqa 1, Jordan in particular, sea club rush (*Bolboschoenus maritimus*), a species common across Southwest Asia, was found to have a repeated presence in hearths, indicating it was a regular part of Natufian plant food based subsistence (Arranz-Otaegui *et al*., 2018b; Wollstonecroft *et al*., 2011).

Abu Hureyra in Syria, is most famous for providing the earliest evidence of agriculture but the Epi-palaeolithic levels indicate evidence of extensive wild plant exploitation. The location of this site was near water at the conjunction of riverine forest and woodland-steppe and close to park-woodland. The presence of wild wheat and ryes cereals, and the possibility that domesticated cereal species were bred from these 'founder crops', has meant that they have been the main focus of the publications about Abu Hureyra. However, the site also yielded starch tubers and rhizomes of club-rush (*Scirpus maritimus*), bistort (*Polygonum* sp.), sea-club rush (*Bolboschoenus maritumus*) asparagus (*Asparagus* sp.) and other unidentified roots and tubers, as well as the usual acorns (*Quercus* spp.) pistachios (Pistachia) and almonds *(Amagdalus* sp.) (Arranz-Otaegui *et al*., 2016; Hillman, 2000) .

4.7.2 South Asia

Table 4.3: Sites of starchy plant macro-remain finds from hunter-gatherer sites in South Asia.

South Asia	**Age (kya)**	**Period**	**Type of Plant Remain**	**Reference**
Batadomba-lena Rockshelter, Sri Lanka	36	Upper Pal.	Charred nuts and tubers	Perera *et al*., 2011
Beli-Lena, Sri Lanka	32	Pleistocene	Charred nuts, wild bananas and wild breadfruits	Kajale, 1989
Karnataka and Andhra Pradesh, South India	4.8-3.2	Neolithic	Charred seeds and tubers	Fuller *et al*., 2004

Archaeobotanical research in the Pleistocene era in South Asia is increasing but published research is currently limited to hunter-gatherer sites in Sri Lanka (Table 4.3). Fuller indicates that food production began among mobile and sparsely populated groups, some of which persisted into the mid Holocene (Fuller, 2014). The only available data come from the cave sites of Beli-lena, Kitulgala, 38 km east of Columbo in Sri Lanka (Kajale, 1989) and from Batadomba-lena

Rockshelter, 85 km from southeast of Columbo (Perera *et al*.,2011). . Beli-lena Cave and Batadomba-lena Rockshelter provide charred macro remain evidence of wild breadfruit (*Artocarpus* nobilis Thw.), two species of wild banana (*Musa balbisiana* and *Musa acuminate*), nut shells of *Canarium zeylanicum*, and unidentified charred parenchyma, all sources of either high starch or fatty carbohydrates (Kajale, 1989; Perera *et al*., 2011). These findings indicate the importance of tree fruits and nuts in providing the starch diet of the late Pleistocene hunter-gatherer diet in this region. Pits, similar to those described first at Niah Cave, Borneo, were uncovered in the 15 kya levels and are considered to have been used for the detoxification process for nuts (Barker *et al*., 2007; Perera *et al*., 2007). In Southern India, whilst the examples from Karnataka and Andhra Pradesh are from the Neolithic, the sequences illustrate the impact of the transition from a subsistence based on foraged tubers in the earlier levels, which were replaced by cultivation of cereals, especially millets, and pulses that increase in frequency through the upper levels. This later cultivated plant diet was supplemented by foraged plant foods (Fuller *et al*., 2004).

4.7.3 East and Southeast Asia

Table 4.4: Sites of starchy plant macro-remain finds from hunter-gatherer sites in East and Southeast Asia.

East and Southeast Asia	**Age (kya)**	**Period**	**Type of Plant Remain**	**Reference**
Zengpiyan, China	12k-7	Upper Pal.	Charred parenchyma	(Zhao, 2011)
Higashi-Kurotsuchida, Japan	13.6 -0.3	Incipient Jomon	Water-logged walnuts and acorns from storage pits and charred	(Kawashima, 2016; Kobayashi, 2004; Mitsunaga, 2006; Sakaguchi, 2009)
Niah Cave, Sarawak, Borneo	50k	Upper Pal.	Charred parenchyma, nuts, fruits and seeds	(Barker *et al*., 2007; Barton and Paz, 2007; Barton *et al*., 2016)
Baguia & Baucau, Timor Leste	16-17	Upper Pal.	Charred Parenchyma prob. Taro and Yam	(Oliveira, 2012)
Pasimbahan-Magsanib site, Northern Palawan, Philippines	10	Mesolithc	Charred seeds, nut fragments, parenchyma	(Ochoa *et al*., 2014)
Ille Cave, N. Palawan, Philippines	16	Upper Pal.	Siliceous plant remains identified on use-wear	Lewis *et al*. 2007
Leang Burung 1, Sulawesi, Indonesia	6	Epi-Pal.	Charred parenchyma	(Paz, 2005b)
Rach Nui, Vietnam	1.5-1.3	Neolithic	Charred parenchyma rush & sedge tubers, fruit	(Castillo *et al*., 2017)

Southeast Asia

The key theme of this region is the prevalence of tubers and rhizomes, from the Palaeolithic onwards (Table 4.4). Roots and tubers are key crops of the tropical latitudes and are easily cultivated (vegeculture) (Fuller *et al*., 2014), whilst cereals are a key theme of the temperate latitudes of southwest Asia. Dominant across most of the southeast Asian sites are fragments of yam (*Dioscorea hispida*) and taro (*Colocasia esculenta*), with later evidence of banana (*Musa* sp.) and breadfruit (*Artocarpus* sp.). The site of Rach Nui, Vietnam, whilst late Neolithic and sedentary, still reflects a very late foraging culture. Plant remains in the form of parenchyma from sedge (*Cyperus* sp.) nutlet tubers and rush rhizomes (*Scirpus* sp.), together with mesocarps and fragments of fruit, formed 28% of the assemblage. Cereals, which were imported, only formed 2%, reflecting more foraging than farming at this site (Castillo *et al*., 2017). The plant evidence was supported by the faunal remains that also reflected more hunting, foraging and fishing than farming. The phytolith analysis from this site also highlighted the presence of bananas, palm and bamboo (Castillo *et al*., 2017).

Research from Niah Cave, Sarawak in Borneo, at 50-27 kya, reflects the other end of the chronological spectrum in a seminal study that combines pollen, starch grain and charred macro-remain evidence to provide a picture of rainforest exploitation. Here the macro-remain evidence of yam (*Dioscorea hispida*) and taro (*Colocasia esculenta*) is present in many levels. Exocarps of breadfruit (*Artocarpus* sp.) and pandanus nuts (*Pangium edule*) also indicate that starchy plants were a significant element of the Palaeolithic hunter-gatherer diet (Barker *et al*., 2007; Barton, 2005; Barton and Paz, 2007; Barton *et al*., 2016; Paz, 2005b). Other than tuber digging and a rich carbohydrate diet, the findings at Niah Cave have drawn attention to two more key aspects of plant diet. The first is the ability to de-toxify plants by processing.

Taro (*Colocasia esculenta*) contains secondary metabolites that are toxic to humans and a piece of raw taro the size of an apple is sufficient to kill an adult (Barker *et al*., 2007: 256) and cooking may have broken down the toxins but further processing may have been required. Excavations at Niah Cave also

revealed intersecting pits with the remains of nuts from the *Pangium edule* tree in the ash. These nuts are highly toxic unless they are processed by burying and then boiling them or burying them in ash for forty days. The pits, it is suggested, are evidence of this processing (Barker *et al*., 2007). Using different methods to detoxify different plants requires knowledge and skill. The right kind of fire would be required and FTIR analysis of these levels would be interesting to discover the temperatures reached.

The second key aspect is that pollen evidence from later levels at Niah Cave suggests forest clearance by burning started ~50 kya (Hunt *et al*., 2016). Increasingly, recent research from Timor Leste, Indonesia and the Philippines indicates extensive exploitation of high energy seeds and tubers (Ochoa *et al*., 2014; Oliveira, 2012; Paz, 2005a).

East Asia

Southern China is defined as south of the Nanling Mountains and has a tropical climate. As in southeast Asia, vegeculture is still widespread today, but rice is the main economic crop (Figure 4.5).

Figure 4.5: Modern rice and taro cultivation, Guilin, Guangxi Province, Southern China. (Image: Cynthia Larbey)

Excavations of three early Neolithic cave sites at Zengpiyan, Xiaojing and Dingsishan in Guangxi Province (12-7 kya) show evidence of the exploitation of seeds, nuts, roots and tubers (Zhao, 2011). Rice does not appear until 6 kya in this region and subsistence patterns before that time appear to contain a substantial quantity of roots and tubers (Zhao, 2011).

There is extensive evidence for the exploitation of arboreal resources for starchy food throughout the Jomon period in Japan. At Higashi-Kurotsuchida, southern Kyushu, excavation has revealed storage and roasting pits associated with charred nut remains dated to the early Incipient Jomon period between 13.6-11.3 kya, attest to the importance of arboreal fruits and nuts in hunter-gatherer societies at this time (Kobayashi, 2004; Sakaguchi, 2009). Walnuts (*Junglans regia*), acorns (*Quercus serrata*) and chestnuts have all been excavated from Jomon sites. The Jomon diet included root crops such as yams with a yam stalk bud from the Early Jomon site of Matsugasaki in Kyoto Prefecture (Kobayashi, 2004) and bracken (*Pteridium aquilinum*) (Mitsunaga, 2006). Whilst the main Jomon crop was acorn, there were preferences throughout this period with chestnuts (*Castanea* sp.) characteristic of the Middle Jomon (Kawashima, 2016). This changing preference may have been a feature of changes in climate from the cold, but warming Late Glacial climate of the Incipient Jomon (13.7-8.5 kya) to the warm climate of the Middle Jomon (5-3.2 kya) (Sakaguchi, 2009).

4.7.4 Australia and Papua New Guinea

Table 4.5: Sites of starchy plant macro-remain finds from hunter-gatherer sites in Australia and Papua New Guinea.

Australia and Papua New Guinea	Age (kya)	Period	Type of Plant Remain	Reference
Madjedbebe, Northern Territory	65	MSA	Charred seeds and tubers	(Clarkson *et al*., 2017)
Cuddie Springs, New South Wales	30	LSA	Grinding of grass seeds (phytoliths from grindstones)	(Fullagar and Field, 1997)
Carpenter's Gap, Southern Kimberley Ranges, Western Australia	40-24	MSA	Charred seeds and tubers	(McConnell and O'Connor, 1997)
Kosipe Mission, Papua New Guinea	40-50	Palaeolithic	Charred Pandanus nut shells	(Fairbairn *et al*., 2006; Summerhayes *et al*., 2010)

It is argued that humans reached the Sahul, the former landmass that included Australia, Papua New Guinea and Tasmania (Figure 4.6), around 70 kya (Dortch and Malaspinas, 2017). This date corresponds with the date of the early occupation of Madjedbebe rock shelter in Northern Australia considered to be ~65 kya (Clarkson *et al*., 2017).

Figure 4.6: Sahul landmass. (Image: adapted from Wikimedia Commons)

The macro-fossils of *Pandanus* sp. nuts and vegetative parenchyma from roots and tubers have been recovered from hearths and general sediment matrix at Madjedbebe (Clarkson *et al*., 2017: SI 6: 62-65) (Table 4.5). These plant remains are probably the oldest evidence of cooked plant starches outside Africa.

Between 40-24 kya, communities at Carpenter's Gap, southern Kimberley, Western Australia, utilised significant quantities of plant foods that include fruits, seeds and tubers. Tubers and seeds formed a significant proportion (although not specified) of the plant macro-fossils, the density of which were 2,000 fragments per square metre, although no depth measurement is given (McConnell and O'Connor, 1997). The species identified were a mixture of fruit, nuts, seeds and roots and tubers (See Table 4.6).

Table 4.6: Archaeological plant species from Carpenter's Gap, compiled from data in McConnell and O'Connor (1997).

Species	Common Name	Family	Comments
Adonsonia gregorii	Baobab	Malvaceae	Fruit
Terminalia catappa	Tropical almond	Cambretaceae	Nut
Ampelocissus acetosa	Wild Grape	Vitaceae	Fruit for water and tuberous root for food
Vitex glabrata	Chastetree	Lamiaceae	Fruit and medicine
Chenopodiaceae		Chenopodiaceae	Seeds
Cyperus sp.	Sedge	Cyperaceae	Seeds and nutlets

Evidence of processing of phytolith-containing plants on twenty-five grinding stones from Cuddie Springs, central New South Wales of 30 kya came from a Bunuha Aboriginal settlement around an ephemeral fresh water lake within a semi-arid zone. It is suggested that these grindstones were used for processing grass seeds (Fullagar and Field, 1997).

In Papua New Guinea evidence has been found of early human presence 44-30 kya at an open air site near Kosipe Mission. This site has produced evidence of exploitation of *Pandanus* nuts, where charred shells of these nuts were consistently found in close association with charcoal, stone tools and bone fragments (Fairbairn *et al*., 2006; Summerhayes *et al*., 2010). The presence of yams has been attested by the presence of starch granules connected with stone tools but no method was published and prior to the publication of the new methodology for handling starch in the archaeological record in 2014 (Crowther *et al*., 2014), contamination, therefore, may be an issue.

4.7.5 Canada and the Americas

Table 4.7: Sites of starchy plant macro-remain finds from hunter-gatherer sites in Canada and the Americas.

Location	Age (kya)	Period	Type of Plant Remain	Reference
Pacific NW Coast, Canada	5.7-4.2	Late/Middle Component	Water-logged arrowhead tubers	Hoffman *et al*., 2016
EeRb140, Interior Plateau, British Columbia	0.8-0.2	Late Period	Charred macro remains	Wollstonecroft, 2002
Sts'Ailes (Chehalis), Harrison River, British Columbia	1.2		Charred camas tubers from earth ovens	Lyons & Ritchie, 2017
Gerstle River and Upper Sun Valley, Alaska	~14	Pre Clovis	Charred seeds	Holloway, 2016
Dryden Cave, Gt. Basin, Nevada	8k-6k	Early Archaic	Semi-acquatic monocot tubers from coprolites	Neumann *et al*., 1989
Clauson Site, New York	8	Late Archaic	Charred parenchyma	Levine, 2004
LSP1 Rockshelter, South Central Oregon	10-7.6	Early Archaic	Charred and uncharred seeds	Kennedy and Smith, 2016
Edwards Plateau & Post Oak Savannah,Texas, USA multiple locations	8kya-9kya	pre-Columbian	Charred roots and tubers from ovens	Dering, 1999; Thoms, 1989, 2008, 2009
Cuncaicha rock shelter, Pucuncho Basin, Peruvian Andes, Peru	12.4-11.5	Upper Pal.	Charred unid parenchyma	Rademaker *et al*., 2014
Monte Verde, Chile	12.8-12.4	Upper Pal.	Charred and desiccated potato tuber remains	Ugent 1997; Ugent *et al*., 1987

aDNA research has forwarded the most likely hypothesis that humans entered America over the Bering land bridge (The Beringia hypothesis) (Pedersen *et al*., 2016). Archaeological and genetic evidence agree that the earliest migrations were ~23-24 kya (Figure 4.7) (Bourgeon *et al*., 2017; Raghavan *et al*., 2015). New dates from Bluefish Caves, Yukon Territory, Canada show human occupations (Ancient Beringians) in this territory ~24 kya (Bourgeon *et al*., 2017) at the height of the LGM. The ancestors of all Native Americans appear to have migrated into and through America from Siberia in one wave (Figure 4.7), placing humans as far south as Chile by 14.5 kya (Ugent, 1997). The routes of the migrations south are still under debate (Sills, 2018).

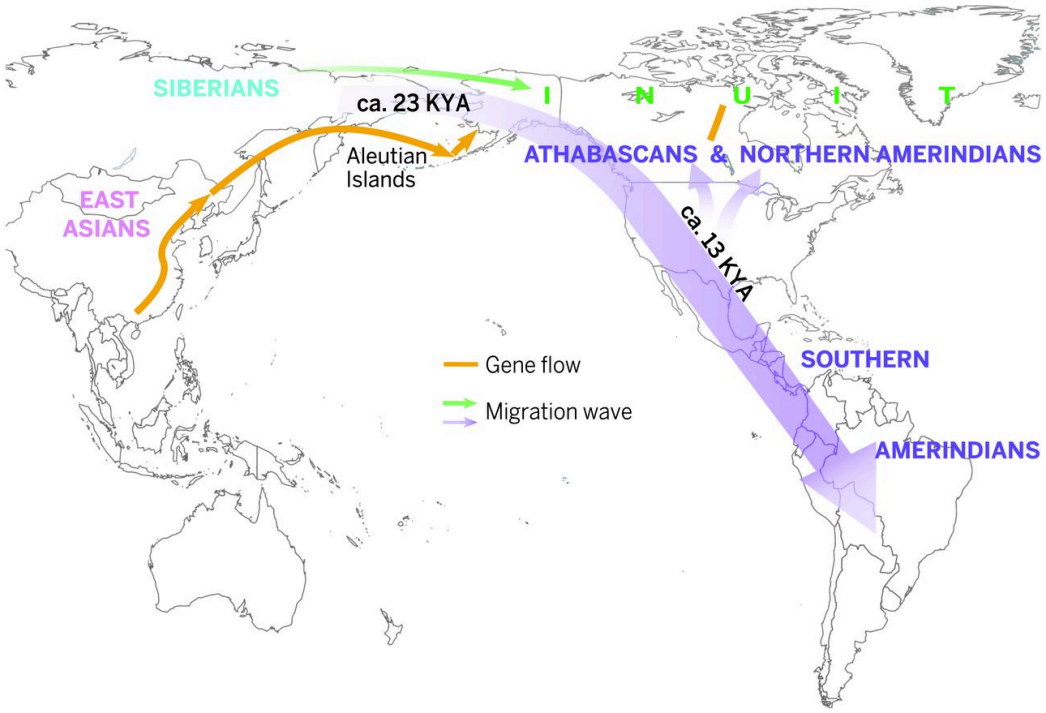


Figure 4.7: The ancestors of all Native Americans entered the Americas as a single migration wave from Siberia (purple) no earlier than ~23 ka, separate from the Inuit (green), and diversified into "northern" and "southern" Native American branches ~13 ka. There is evidence of post-divergence gene flow between some Native Americans and groups related to East Asians/Inuit and Australo-Melanesians (yellow). (Map taken from Raghavan *et al*. (2015: 841)

The archaeobotanical evidence throughout the Americas points to a knowledge of berries, seeds and roots and tubers and processing techniques (Table 4.7). This knowledge had either been re-acquired or the span of time spent migrating through ice and Arctic tundra had been fairly rapid and this knowledge had been retained from the Old World.

The archaeobotany from the ancient Beringian sites of Gerstle River and Upward Sun Rivers, Alaska (~14 kya) appears to reflect a plant diet similar to that of Inuit groups today, that is, one dominated by seasonal berries. The assemblages from these sites were dominated by bearberry (*Arctostaphylos uva-ursi*), although they also included other berries, sedge and tree buds (Holloway, 2016).

In the rest of the Americas, whilst the acquisition of berries and seeds are ubiquitous in the archaeobotanical analyses, roots and tubers are an important part of the diet and there are two key themes in the evidence.

The first theme is the exploitation of the vegetation associated with rivers and water. The tubers of predominantly monocot rushes (*Typha latifolia*), sedges (*Scirpus* sp.), arrowhead (*Sagittaria sagittifolia*), camas lilies (*Camassia quamash* and *C. leichtlinii*), and water lilies (seeds and tubers) (*Nymphaea odorata*) are found in archaeological sites throughout North America and Canada (Hoffman *et al*., 2016; Levine, 2004; Lyons and Ritchie, 2017; McWeeney, 2007; Neumann *et al*., 1989). In the case of a 3,800 year old wetland garden in British Columbia, Canada, the waterways had been engineered and a paved wetland was created to cultivate arrowhead tubers (*Sagittaria sagittifolia*), a tuber used not just for subsistence but by this time stored and traded by this indigenous community (Hoffman *et al*., 2016). This site displays not just botanical knowledge but engineering and water management. Water must have been the key resource; any mobility pattern, migration and settlement must have been determined by water. It may also provide the answer to the question of how humans navigated the comparatively barren regions of the boreal zone: by navigating water ways. It is noted that these roots and tubers have a specific kind of parenchyma, adapted to allow for pockets of air in water margins or in water itself, called aerenchyma.

The second theme in North America is the presence of earth ovens from ~9 kya (Dering, 1999; Thoms, 1989; Thoms, 2008; Thoms, 2009). The ovens were used initially just for the cooking of roots and tubers, although later some are also used for cooking meat (Thoms, 2009). Throughout the southern plains and southeastern woodlands the number of earth ovens increase, with onions (*Allium* sp.) and camas lilies (*Camassia* sp.) being cooked in oak savanna regions and agave (*Agave lechuguilla*) and stool (*Dasylirion* sp.), above ground species, in drier savannas (Dering, 1999; Thoms, 2008). Camas lily tubers contain inulin, a complex sugar polysaccharide based on fructose, which would have taken several days of cooking to be digestible (Lyons and Ritchie, 2017) and earth ovens would have been ideal for this process. Thoms argues for earth ovens allowing the intensification of growing camas lilies (Thoms, 1989). A number of species associated with hunter-gatherer foraging required substantial processing to ensure they were edible. Sunflowers (*Helianthus annus*) and Jerusalem artichokes (*Helianthus tuberosum*) that were both subsequently domesticated in North America contain inulin. Acorns from most species of oak (*Quercus* sp.) contain tannic acid and would need to be

leached or roasted before eating (Arnason *et al*., 1981; Driver, 1952; Incoll *et al*., 1989; Pickersgill, 2007; Turner *et al*., 2003; Wandsnider, 1997) and earth ovens would have played an important role in this process.

Central America has few hunter-gatherer sites of any age depth but from this region comes the domestication of a number of starchy plant species that are an everyday part of today's diet, Mexican bean yam (*Pachyrhizus ersus*), squashes and pumpkins (*Cucurbita* sp.), sweet corn (*Zea mays*), and, from the Caribbean, sweet potato (*Ipomoea batatas*) (Fuller *et al*., 2014; Pickersgill, 2007; Piperno *et al*., 2007). Mesoamerican evidence for the use of sweet and chilli peppers (*Capsicum annum*) 6 kya in Guila Naquitz and Silvia's Cave, Mitla near Oaxaca, Mexico (Perry and Flannery, 2007), and pumpkin (*Cucurbita pepo*) and bottle gourd (*Lagenaria siceraria*) 8 kya from Coxcatlan Cave, Mexico (Smith, 2005) would suggest that pre-Columbian uses for these plants existed. It is also interesting to note that one of the key areas outside of Africa for salivary amylase gene duplication is from this region, where ten copies of AMY1 are more usual than the human ancestral six copies (Inchley *et al*., 2016).

In South America, past hunter-gatherer plant food is characterised by the exploitation of wild, but highly toxic tubers that were ultimately domesticated: the potato and manioc. The potato was domesticated in South America but foraged, processed and cooked as a wild variety (*Solanum maglia*) before the subsequently domesticated *Solanum tuberosum*. Fragments of ancient wild potato tubers have been found in archaeological contexts in early hunter-gatherer sites dated to 13 kya in Monte Verde, Chile. The evidence was found in the form of preserved skins and starch granules (Ugent, 1997; Ugent *et al*., 1987). Unidentified parenchyma fragments were also found at 4480 meters above sea level (masl) in the Peruvian Andes, although such plant remains were considered to have been collected at lower altitudes, and dated to 12.4-11.5 kya (Rademaker *et al*., 2014).

The domestication of possibly one of the most toxic species also took place in Amazonia, South America, that of manioc (*Manihot esculenta*). The more starch-rich variety of manioc or cassava (the sweet variety is slightly less toxic) contains cyanogenic glucosides, which if not processed properly can cause neurological

damage in a disease called konzo. Manioc requires leaching, drying and fermentation to reduce the cyanide to safe levels (Cardoso *et al*., 2005; Fuller *et al*., 2014). Archaeological phytolith evidence shows manioc exploitation dating to 2.8-2.4 kya at the Real Alto site, Ecuador (Chandler-Ezell *et al*., 2006).

The time difference between human colonisation of the New World and the subsequent appearance of species being cultivated or domesticated was small.

4.7.6 Europe

Table 4.8: Sites with starchy plant macro-remain finds from hunter-gatherer sites in Europe.

Europe	Age (kya)	Period	Type of Plant Remain	Reference
Dolní Věstonice, Czech Republic	30	Upper Pal.	Charred parenchyma	(Beresford-Jones *et al*., 2011; Mason *et al*., 1994; Pryor *et al*., 2013)
Hohle Fels Cave, Swarbia, Germany	40-15	Upper Pal.	Charred seeds	(Riehl *et al*., 2014)
Buran-Kaya III, South Crimea, Ukraine	37.8-33.1	Upper Pal.	Carbon and Nitrogen Isotopes	(Drucker *et al*., 2017)
Mezhirich, Ukraine	22	Upper Pal.	Charred seeds and berries	(Soffer *et al*., 1997)
Cova de les Cendres, Tieulada-Moraira, Alicante, Spain	14-14.5	Magdalenian	Charred seeds and fruits	(Varea and García, 2017)
Santa Maria, Spain	12k-9	Epi-Pal.	Charred fruits and seeds	(Aura *et al*., 2005)
Franchthi Cave, Greece		Pal.-Mesolithic	Charred seeds and nuts	(Hansen, 1991)
Calowanie, Poland	11.3-8.3	Mesolithic	Charred parenchyma	(Kubiak-Martens, 1996)
Rotterdam, Netherlands	7.3-6.7	Mesolithic	Charred acorns, hazelnuts, water chestnuts, water lily	(Kubiak-Martens *et al*., 2014; Zijl *et al*., 2011)
Colonsay, Scotland	6.6-6.5	Mesolithic	Charred hazelnut shells, lesser celandine tubers, crab apples	(Mason and Hather, 2000; Mithen *et al*., 2001)
Halsskov, Denmark	4.8 -6.4	Mesolithic	Charred parenchyma	(Kubiak-Martens, 2002)
Tybrind Vig, Denmark	5.6-4	Mesolithic	Charred parenchyma	(Kubiak-Martens, 1999)

The Last Glacial Maximum (LGM) (26.5-19 kya) would have made parts of northern Europe uninhabitable and others cold and dry. Even the warming of the climate around 15 kya would have been followed by peaks of severe cold until the final warming around 14-13 kya (Clark *et al*., 2009). Throughout the Mediterranean, the climate would have been cold and very dry, borne out by the seed findings from Palaeolithic Zone 1 (25-17 kya) in Franchthi Cave, Greece. The seeds found during this period were dominated by alkanet (*Akanna* sp.), but also gromwell (*Lithospermum arvense*) and *Anchusa* sp., all low growing species found

on rocky outcrops (Hansen, 1991). It is likely, however, that this region saw the largest population density during the LGM and an indicative model of population can be seen in Figure 4.8 (Tallavaara *et al.*, 2015).

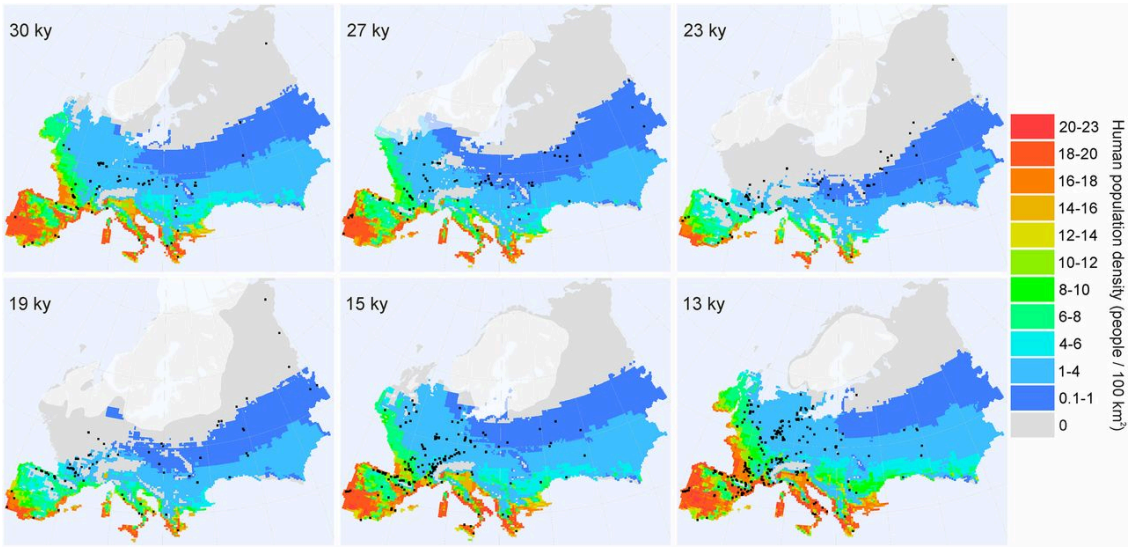


Figure 4.8: Simulated human population range and density across Europe compared with the spatial distribution of archaeological sites during six time intervals from 30 to 13 ky ago. Archaeological sites are indicated with black dots and in each time slice they represent sites dated within 1,000-y bins. Image taken from Tallavaara *et al*. (2015: 8234)

Archaeologists are beginning to understand the impact on humans of the climate in this period (Gamble *et al.*, 2004) and the apparent 'explosion' of Mesolithic and Epi-Palaeolithic sites, finds and archaeobotanical remains is attributable largely to the climate dynamic of Europe (Table 4.8). The three Upper Palaeolithic sites for which there is evidence are dated to an inter-stadial period before the LGM. They are important as much for their archaeobotanical methods as their rarity: Buran-Kaya III, Ukraine, Dolní Věstonice II, Czech Republic and Hohle Fels, Germany.

The Buran-Kaya III rock shelter is located in the eastern bank of the Burulcha River in the Belogorsk region of Crimea, Ukraine (40-29 kya) (Drucker *et al.*, 2017). The nitrogen isotope analysis of bone collagen from three human fossils, from layers dated to 37.8 to 33.1 ka cal BP, addressed the frequent interpretation of a high 15N (N = nitrogen) reading as consumption of freshwater resources. The research showed that phenylalanine and glutamic acid and the nitrogen isotope ratio reflected the contribution of plant proteins in the diet as well as terrestrial meat, and that a significant proportion of that meat probably came from

mammoths (Drucker *et al*., 2017). This is a rare and important contribution to understanding the role of plants in the Palaeolithic diet in eastern Europe using isotope methods.

The consumption of mammoth and plants is the theme of the findings from Dolní Věstonice II, Czech Republic. Dolní Věstonice II lies on a hill side of a valley that runs between the Carpathian Mountains and the Bohemian Plateau, which forms a natural corridor known as the Moravian Gates (Beresford-Jones *et al*., 2010; Svobodá, 2000). Here hunter-gatherers hunted herds of mammoth (*Mammuthus primigenius*) and reindeer (*Rangifer tarandus*) migrating from northern Asia to Europe and the sites of Dolní Věstonice I, Pavlov sites and Předmostí´ provide some of Europe's best archaeological evidence of mammoth hunting and the Gravettian culture 40-30 kya (Beresford-Jones *et al*., 2011; Svobodá, 2000). Dolní Věstonice II lies, not with the other kill or butchery sites on the valley floor, but halfway up the hill. Initial screening of one archaeobotanical sample from a hearth provided evidence of wood charcoal and indicated the possible cooking and consumption of starchy plants (Mason *et al*., 1994). The excavation at Dolní Věstonice II in 2005 focussed on the recovery of archaeobotanical remains. The 10 x 20 m site was excavated in 50cm squares, giving spatial resolution and 100% of the fill was floated to recover charred plant remains. The findings from the subsequent analyses showed significant levels of parenchyma (Beresford-Jones *et al*., 2011; Pryor *et al*., 2013). Further spatial analysis revealed a correlation between the high densities of parenchyma fragments and those of vertebrate remains and lithics in and around the hearth (Larbey, 2013). These results offered the oldest direct evidence in northern Europe of hunter-gatherers cooking and consuming starchy plants 30 kya.

Almost at the other end of the Moravian Gates 700 km to the east is the site of Hohle Fels in southwestern Germany. This project conducted pollen, phytolith and macro-fossil screening for the entire Aurignacian, Gravettian and Magdalenian sequence. This sequence spanned 44.2-15 kya. The evidence from the Aurignacian and Gravettian sequences (44.2-33 kya) shows an interesting similarity with the

diet from Alaska, being dominated by bearberry seeds (*Arctostaphylos* sp.) (Riehl *et al*., 2014).

Combined with the putative plant processing tools, such as grinders, pestles, scrapers and anvils from Kostenki, Russia from the Dnestr region (Soffer and Praslov, 1993), these three examples show that plant foods probably formed part of the Upper Palaeolithic diet. The climate was highly variable throughout this period in northern Europe. Climate oscillations between cold and warm, known as Dansgaard- Oeschger (DO) events (of which there were at least six in the Gravettian), meant that the air temperature could vary by 15°C within a few decades. The climate would have impacted on plants and animals, and human subsistence patterns, but plants were clearly gathered and cooked and eaten throughout this period.

Archaeobotanical analyses have been more frequent in studies of sites post-dating the LGM. At Franchthi Cave, Greece (at levels dated from 12.5 kya), there is evidence of pistachios (*Pistachia* sp.) and almonds (*Amygdala* sp.) (Hansen, 1991). In Spain, at the sites of Cova de les Cendres (14-14.5 kya) and Santa Maria (12-9 kya), there is evidence of consumption of seeds and fruits (Aura *et al*., 2005; Varea and García, 2017). In northern Europe, parenchyma evidence from pre-agrarian contexts attests to starchy plants as a routine part of the hunter-gatherer diet: Calowanie, Poland (11 kya) (Kubiak-Martens, 1996) and three Mesolithic sites in the north-western part of the Netherlands, Keinsmerbrug, Mienakker and Zeewijk, where evidence included acorns, hazelnuts and water chestnuts (7 kya) (Kubiak-Martens *et al*., 2015; Kubiak-Martens *et al*., 2014; Zijl *et al*., 2011). From Colonsay, Scotland (6.5 kya) there is evidence of the exploitation of celandine tubers (*Ficaria verna*); evidence of the consumption of these tubers has been found throughout the Neolithic across Denmark and northern Germany (Klooss *et al*., 2016; Out and Dörfler, 2016). And in Denmark from Tybrind Vig and Halsskov parenchyma is further testimony to a starchy plant diet 4-6 kya (Kubiak-Martens, 1999; Kubiak-Martens, 2002).

However, despite the strong climate-linked narrative connected to the LGM in Europe, evidence for plant foods as part of the hunter-gatherer carbohydrate diet is evidenced from the Upper Palaeolithic/Mesolithic and even into the Neolithic. Exploitation of species such as bearberry (*Arctostraphylos* sp.) also shows a potential Old World botanical knowledge continuity with that of the New World. And the exploitation of roots and tubers from Dolní Věstonice II would suggest that riparian vegetation could provide potential year-round plant food sources (Larbey, 2013)

4.7.7 Africa

Table 4.9: Sites with starchy plant remains from hunter-gatherer sites in Africa.

Africa	**Age (kya)**	**Period**	**Type of Plant Remain**	**Reference**
Klasies River, South Africa	102-98	MSA	Starch granules in fossil dental calculus - grass seeds and USO	Henry *et al*., 2014
Blombos Cave, South Africa	99-70	MSA	Starch granules in fossil dental calculus - grass seeds and USO	Henry *et al*., 2014
Sibudu, South Africa	77	MSA	Charred Seeds and rhizomes	Sievers, 2006, Sievers and Muthama Muas, 2011
Various sites, South Africa	11-110	MSA & LSA	Charred and phytolith evidence of grass seeds but some roots and tubers	Nic Eoin, 2016
Boomplaas, South Africa	43	LSA	Charred plant remains and fruits	Deacon, H. J., 1995
Highlands Rockshelter, South Africa	30	LSA	Desiccated plant remains in cave	Deacon, H. J ,1976
Strathalan B, South Africa	22	LSA	Charred and dried corms	Opperman and Heydenrych, 19
Melkhoutboom Cave, South Africa	6	LSA	Dried bulbs - stored in cave	Deacon, H. J., 1976
Scotts Cave, South Africa	0.76-0.36	Late LSA	Desiccated plant remains in cave	Deacon, H. J., 1993
Sehonghong Shelter, Lesotho	>25	Early LSA	Charred and dried geophytes	Carter *et al*., 1988, Mitchel, 1996
Grotte des Pigeons, Taforalt, Morocco	15-13.7	Upper Pal.	Charred plant remains Acorns, pine nuts, legumes and wild grasses	Humphrey *et al*., 2014
Haua Fteah, Libya	12.6-7.9	Caspian	Charred large-seeded legumes, fruits and berries	Barker *et al*., 2010
Al Khiday, Sudan	6.7	Neolithic	Starch granules in fossil dental calculus Cyperus tubers	Buckley *et al* ., 2014

It is suggested that the earliest AMY starch digestion gene duplication took place in Africa, but before humans started genetically to diversify, *i.e*. one small haplogroup 300 kya in Africa (Inchley *et al*., 2016). There is much debate about the timing and geography within Africa of the emergence of the first *Homo sapiens*. But much of the debate hinges on morphology and whether the human

fossils are fully anatomically human (AMH) (Grine *et al*., 2017; Hublin *et al*., 2017; Klein and Scott, 1986; Richter *et al*., 2017). Despite this debate, it appears from the genetic analysis that, regardless of morphology, it appears that early *Homo sapiens* may well have duplication amylase genes (Inchley *et al*., 2016).

Currently, the best known earliest human occupation sites are located across South Africa (see Figure 1.1 in Chapter 1), with many falling into the Late Pleistocene MIS 5e climate range, such as Pinnacle Point (170 kya) and Klasies River (120 kya) along the Cape coast of South Africa.

Despite human colonisation throughout all African environments (and across the world) and a great variation of technologies and environments, the dominant focus of deep time research has remained on stone tool-mediated hunting for meat (Badenhorst and Plug, 2012; Badenhorst *et al*., 2016; Klein, 1976; Lombard, 2007; Van Pletzen, 2000; Villa and Soriano, 2010). Along African Cape coastal MSA/Middle Palaeolithic sites, there is also extensive evidence for early humans foraging for shell fish and exploitation of marine resources at three key locations: Ysterfontein (Avery *et al*., 2008; Klein *et al*., 2004; Wurz, 2012), Klasies River Mouth (Marean and Binford, 1986; Thackeray, 1988) and Pinnacle Point (Marean, 2010; Marean *et al*., 2007; Nelson-Viljoen and Kyriacou, 2016). Along the North African coast, and at Haua Fteah in particular, recent research has identified seasonal exploitation of shellfish (Klein and Scott, 1986; Prendergast *et al*., 2016).

In the South African LSA the direct evidence for plant foods is as follows: Dried corm scales and corm bases of edible geophyte species such as lilies (*Watsonia* sp., Iridaceae), leaf sheaths of African potato (*Hypoxis* sp., Hypoxidaceae) and sedge tubers (*Cyperus usitatus*) have been found stored in dry areas of Scott's Cave (0.7-0.3 kya), Melkhoutboom caves (6 kya), Strathalan B cave, Highlands rock shelter (30 kya) and dry and carbonised remains identified at Boomplas cave (43 kya) in South Africa (Deacon, 1976; Deacon, 1993; Deacon, 1995; Opperman and Heydenrych, 1990) (see Tables 4.9 and 4.10).

Table 4.10: LSA Plants by South African site. (Table adapted from Deacon, 1972: 37)

Site	**Hoffman's Cave**	**Scott's Cave**	**Springs Shelter**	**Melkhoutboom Cave**	**Highlands Rock Shelter**	**Tafelberg Hall Shelter**
Habitat/ Locality	Coast (Robberg) 50' asl	Coastal Valley 220' asl 20 km inland	Cape Folded Belt 2k' asl, 50 km inland	Cape Folded Belt 2.5k' asl 50 km inland	Interior Plateau 4.35k' asl 230 km inland	Interior Plateau 4.5k' asl 280 km inland
Dating/ associations	3.6-4 kya	1.2-0.3 kya (pottery)	pottery associated	pottery associated	potter associated and pre-pottery occurrences	potter associated and pre-pottery occurrences
Bedding	*Zostera capensis*	*Danthonia* sp.	Grasses	*Themeda triandra* & *Koeleria cristata*	Grasses	not recorded
Raw materials	Not recorded	*Cyperus textilis*	*Cyperus textilis, Phragmites communis,* worked wood	*Cyperus textilis, Phragmites communis,* worked wood	*Cyperus textilis, Phragmites communis,* worked wood	not recorded
Main edible plants	Not recorded	*Watsonia* sp., *Freesia* sp., *Cyperus usitatus, Schotia afra, Amarantus* sp., *Harpephyllum caffrum*	*Watsonia* sp., Freesia sp, *Moraea* sp., *Schotia afra, Oxalis* sp.	*Hypoxis* sp., *Watsonia* sp., *Freesia* sp., *Moraea* sp., *Bulbine alooides, Oxalis* sp. *Cyperus usitatus, Schotia afra, Harpephyllum caffrum*	*Cyperus usitatus, Bulbine alooides, Freesia* sp.	*Cyperus usitatus, Bulbine alooides*

The recent re-assessment and dating of digging sticks and digging stick weights comparable with those used by contemporary San people have dated to 35-40 kya the LSA levels at Border Cave, South Africa. This is significantly earlier than previously considered and provides indirect evidence of routine root and tuber exploitation (d'Errico *et al*., 2012).

Outside of South Africa, starch granule evidence from human fossilised dental calculus from the site of Al Khiday, Sudan also has shown consumption of Cyperaceae tubers into the Neolithic, 7 kya (Buckley *et al*., 2014). Evidence from Morocco, North Africa at Grotte des Pigeons, Taforalt (15-13.7 kya) and Haua Fteah in the Epi-Palaeolithic/Caspian phases, shows cooking and consumption of legumes, grasses, *Cyperus* tubers and arboreal resources such as acorns (*Quercus* sp.) and pine nuts (*Pinus pinea*) (Barker *et al*., 2010; Humphrey *et al*., 2014).

Much of the archaeobotanical research conducted in MSA sites across South Africa has been directed at large-scale landscape and/or climate reconstruction,

with charcoal and pollen the main sources of evidence: Diepkloof (Cartwright, 2013), Elands Bay Cave (Parkington *et al*., 2000), and Sibudu (Allott, 2006). Phytoliths were used to reconstruct the environment over a deep sequence at Pinnacle Point (Albert and Marean, 2012) and, at Sibudu Cave (77 kya), layers of sedge with sedge rhizomes were identified through micromorphology and charred rhizome remains in layers of bedding (Goldberg *et al*., 2009; Wadley *et al*., 2011). The sedge rhizomes (*Cladium mariscus*) were later identified as potential food plants (Sievers and Muthama Muasya, 2011).

The evidence for grass seed exploitation and the tools such as grindstones is ubiquitous and present through most MSA/LSA sites in South Africa (Nic Eoin, 2016).

Evidence for AMH starch consumption in the MSA has hitherto relied upon seeds and sedge tuber interpretation from Sibudu (77 kya) and starch granules captured within fossilized dental calculus and tools from the MSA sites of Klasies River and Blombos Cave (Henry *et al*., 2014) on the Cape coast of South Africa.

4.8 Conclusion

Homo sapiens evolved to be omnivorous. There is extensive evidence for hunting subsistence and indirectly of their protein diet from the stone tools, weapons they used for hunting and from vertebrate remains. From the research and findings presented in this chapter, there is also important evidence for plant foods, and starchy plant foods in particular, making a significant contribution to the diet of hunter-gatherers from 70 kya – 5 kya. Regardless of method, however, there is an obvious gap in our knowledge. Despite the genetic evidence of adaptation to starch from the emergence of humans as a species 300 kya, to date there is no archaeological evidence of their plant or carbohydrate diet. We know more about the plant diet of *Homo erectus* and Neanderthals than about the plant diet of early humans.

Chapter 5

Research Design

5.1 Introduction

The paucity of evidence for the early human starch diet makes it difficult to ask questions about not only one of the key human dietary elements, starch, but about how mobile hunter-gatherers managed their diet in changing ecologies and climates. The lack of research also means that it is not possible to see even the most basic plant processing techniques that might be key to understanding how humans settled in such diverse environments (Hillman and Wollstonecroft, 2016).

Examination of dietary research from great apes has demonstrated that they adapted to different environments. Further, the primate diet has also been shown to be flexible, with nonhuman primates able to identify different foods in different seasons and ecologies, but they have also processed plant foods to sustain their subsistence patterns (Haslam, 2016). Neanderthals also seem to have adapted their diets to varying ecologies, with more dietary diversity seen in southern Europe (Power *et al*., 2018). The level of plant exploitation among the modern humans of the Upper Palaeolithic, Epi-Palaeolithic, Mesolithic hunter-gatherers suggests an extensive flexibility and diversity in plant diet, with the emergence of many processing methods that allowed them to adopt an extremely broad starchy plant diet, supported by food processing niche construction (Hillman and Wollstonecroft, 2016; Wollstonecroft, 2011). Deeper evidence of the human starch diet from the Middle Palaeolithic/Middle Stone Age is limited but also indicates a diet that shows not just diversity but a breadth supported by food processing in an adaptation to the local environment (Barker *et al*., 2007; Dortch and Malaspinas, 2017; Wollstonecroft, 2011).

The design of this research, therefore, needed to address the need to: (a) find the right location to recover deep time evidence for early humans; (b) to ensure that samples were removed from contexts associated with the cooking of food, as opposed to middens, bed burning or simply fuel; (c) to design a method that would be most likely to produce plant remains. This chapter outlines the research and fieldwork behind the decisions about locations, methods and methodology used to answer the research question; and (d) to design an analysis method for the samples that would detect the presence of starchy plant tissue, identify remains if possible to family/genus, and identify processing methods.The identification of processing methods would enable the identification, if present, of interactions between humans, plants and the environment.

5.2 Choice of Sites

At the time of choosing fieldwork sites, the evidence for the emergence of *Homo sapiens* came from East Africa ~200 kya (Lombard, 2012; Morris *et al*., 2014; Stringer, 2003). The evidence from Jebel Irhoud has refined both geographic and temporal discussions around the emergence of humans (Hublin *et al*., 2017). Evidence for early human occupation sites during the MSA are predominantly in South Africa. There are 24 known MSA sites in South Africa (Figure 5.1) with well understood and dated occupations between 140-60 kya.

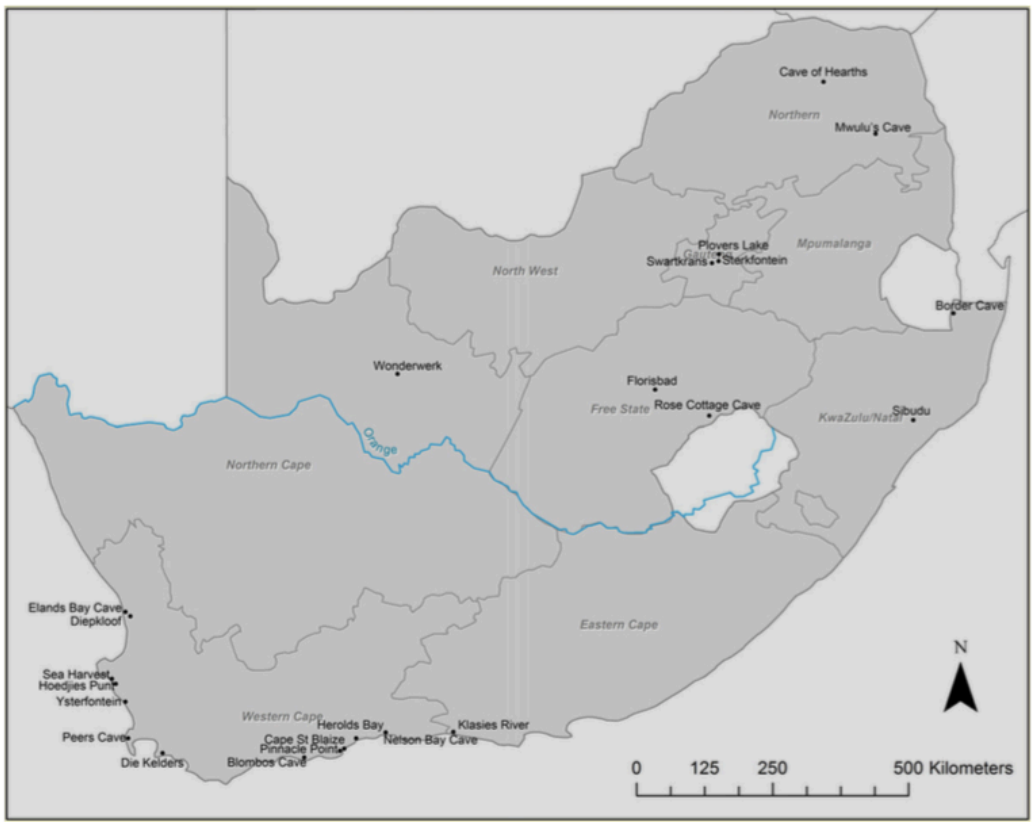


Figure 5.1: MIS 5 MSA Sites in South Africa. (Map from Wurz (2012: 62)

5.3.1 Site Selection Criteria

The site selection criteria were as follows:

(a) They must be recognised early modern human sites, with well-dated sequences.

(b) The possibility of removal of block (untrowelled) sediment samples would be permitted.

(c) Export to the UK for analysis would be permissible.

(d) They would contain observable, intact, hearths in the sections and, if possible, during excavation.

One of the disadvantages for palaeodiet reconstruction is that parenchyma could be the remains of plants already growing in the ground prior to the hearth being created, but if cave sites are chosen, this might be less of an issue; hence (d). The choice of site, sample location and taphonomic control, would, therefore, be key to creating a data set (if it existed) that would represent the starch diet of early modern humans.

At the MSA site of Sibudu 77-58 kya, people constructed plant bedding from sedge grasses and other monocots, which were then covered with aromatic leaves. As part of site maintenance practices, these bedding layers were burned from time to time. The archaeological evidence for this behaviour comes from thick layers of phytoliths, charred and mineralised plant macro-fossils and detailed micromorphological analysis (Goldberg *et al*., 2009; Wadley *et al*., 2011). As part of the bedding layers, fossilised sedge nutlets (*Scleria natalensis*), carbonised sedge nutlet (*Cladium mariscus*) and carbonised rush fruit (*Juncus* sp.) were recovered and considered to be an accidental inclusion from harvesting bedding material (Sievers and Muthama Muasya, 2011; Wadley *et al*., 2011). Such behaviour, although not detected at either Klasies River or Blombos, might be responsible for the ambient presence of parenchyma amongst the general debris of an occupation layer. To be certain that any parenchymous tissue recovered was attributable only to diet, the samples had to come from undisturbed hearths.

In some cases, the shape of the hearth is clear in the archaeological section profile. However, in some instances identification of an undisturbed hearth by eye is not possible or it is not possible to distinguish it from other charred or humified layers and it must be identified by micromorphology analysis (Mentzer, 2012). In all locations reviewed, micromorphology was already being conducted by the same team from Tübingen University, Germany. This proved essential information at Klasies River and is discussed in more detail in the next chapter.

There were potentially four sites that fitted these criteria: Blombos Cave and Klasies River Cave Complex on the Cape Coast; and possibly Klipdrift Shelter, de Hoop Nature Reserve, also on the Cape Coast; and Sibudu Rockshelter, an inland site near Durban in Kwazulu-Natal, South Africa.

5.3.2 Blombos Cave

Blombos Cave is set in the Blombosfontein Nature Reserve on the Western Cape coast (34º 25´ S, 21° 13´ E), overlooking the Indian Ocean, and is one of the most significant MSA sites in South Africa (Figure 1.1).

At 34.5 m above sea level, the site is a wave-cut cave formed in the calcretes of the Wankoe Formation, with the base layer of the cave formed from Table Mountain sandstone of the Cape Supergroup (Henshilwood, 2005). The cave was initially sealed by dune sand but 20cm below the surface aeolian sand deposit, seven phases of occupation have been identified in a stratigraphic sequence of more than three metres; three in the Late Stone Age (LSA) and four in the Middle Stone Age (MSA) (Haaland, 2012). The cave is small, covering a total area of c. 40 m^2 behind the dripline.

The vegetation of this area is variously defined as Fynbos and Renosterveld (Proches *et al*., 2006). Fynbos is defined as natural shrubland or heathland vegetation, and renowned for its endemism and diversity, with over 8,500 species. The Fynbos grows along the Cape of South Africa, where the rain falls in the winter but the summers are hot and dry, so much of the Fynbos vegetation is sclerophyllous, *i.e*. adapted to that a hot and dry climate. Renosterveld is also a shrubland but one that is dominated by *Elytopappus rhinocerotis* (rhino bush), so named because of its grey colour like a rhino. The rhino bush grows on richer soils than Fynbos so is more nutritious (Bergh *et al*., 2014). Behind the cave and for most of this nature reserve, it is Renosterveld but at times with patches of thicket (Figure 5.2), with coastal dune elements nearer the coast line.

Figure 5.2: Thicket near Blombos Cave. (Image: C. Larbey)

Today, there appears to be a distinct vegetation biome immediately around the cave. The plants are different from the surrounding Renosterveld and Albany thicket vegetation, thicket defined by taller shrubs, often succulent and thorny plants that are sensitive to fire and grazing (Bergh *et al*., 2014). The plants around the cave are often succulents and plants which are adapted to rocky slopes, as well as roots and tubers. This forms a natural rock garden and can only be explained by the positioning of the cave being set back in the cliff face and the shadow causing a heavy dew in the early morning that allows these plants to thrive (Figure 5.3).

Figure 5.3: Vegetation around Blombos Cave (Left) view of cave from base of cliff showing green vegetation around cave in possible biome and in the foreground Table Mountain quartz; (right) localized rock garden. (Images: C. Larbey)

Whilst the immediate climate around the cave may not be representative of the palaeoclimate, the plants gave some indication of the potential starchy plant food that is likely to have been available in the vicinity (Figure 5.4).

Figure 5.4: Roots and tubers loosened by heavy rains around the cave at Blombos. (Images: C. Larbey)

Blombos Cave is a well-documented and renowned MSA site because of a series of discoveries made in this small cave (Henshilwood *et al*., 2002; Henshilwood and Marean, 2003). These discoveries included: early bone tools (d'Errico and Henshilwood, 2007; Henshilwood *et al*., 2001a); leaf points of the Still Bay lithic technology (Henshilwood, 2012; Mourre *et al*., 2010; Soriano *et al*., 2015; Villa *et al*., 2009) with evidence of processing ochre, probably for hafting (Henshilwood *et al*., 2011) dated to a period of cooler climate with evidence of changes in subsistence. The discovery of engraved geometric designs on ochre (Henshilwood *et al*., 2009; Henshilwood *et al*., 2002) and abstract drawing on rock in ochre (Henshilwood *et al*., 2018), together with pierced shell beads worn as personal adornment, has initiated discussion about the emergence of personal identity and symbolism (d'Errico *et al*., 2005; Henshilwood *et al*., 2004; Vanhaeren *et al*., 2013). These findings have placed this site at the forefront of discussions on the emergence of complex behaviour and human symbolism from at least 100 kya, at a time when European cave art dated to 40 kya had been the oldest known form of human symbolism (Figure 5.5).

Figure 5.5: Material culture from Blombos Cave includes Still Bay techno-complex, shell beads, bone points and carved ochre and bone. Images: from Choyke (2016), Henshilwood *et al*. (2010), Henshilwood *et al*. (2018)) and the bottom right image (C. Forster)

Although no skeletal human remains have been found at the site, human teeth have been found in sediments dating between 99 - 70 kya (Henry *et al*., 2014).

The profiles in this site show clear combustion features, and there is a micromorphology research programme underway that would make it possible to identify hearths and meet the criteria for site selection (Figure 5.6).

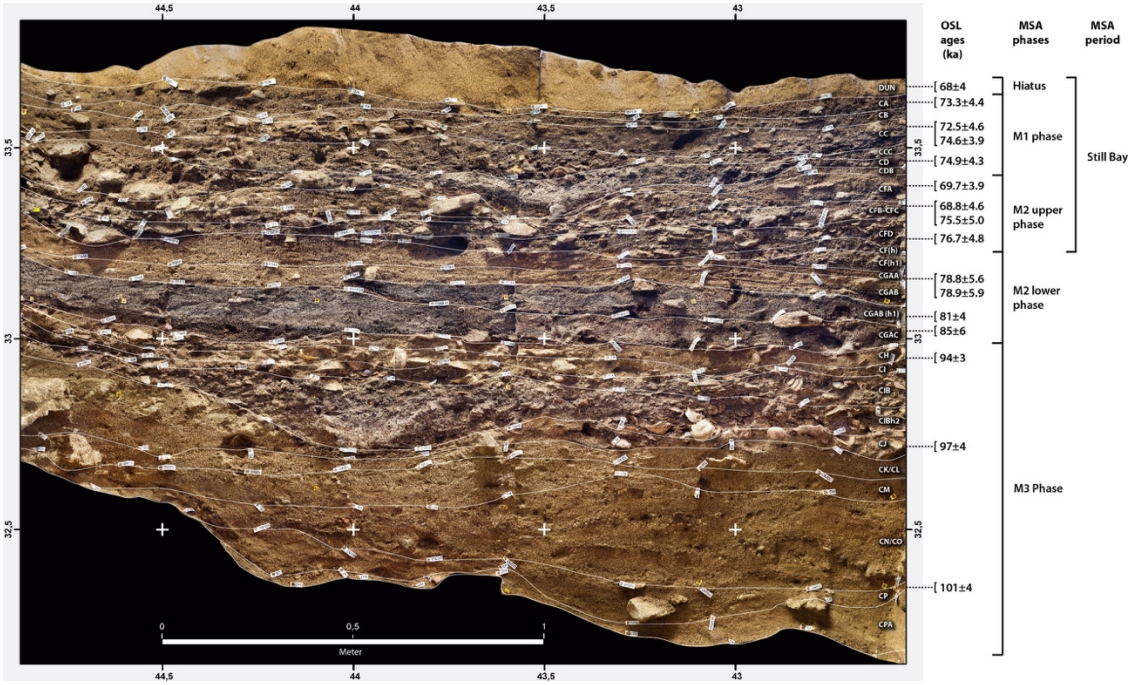


Figure 5.6: South Section Profile, Blombos Cave from the 2013 excavation, together with phases and OSL dating. (Image from Haaland *et al*. (2017)

5.3.3 Klipdrift Cave and Shelter

Figure 5.7: Klipdrift Cave and Shelter overlooking the Indian Ocean. (Image: Magnus Haaland)

This site (34° 27´S 20° 43´E) was identified during the course of a survey of MSA sites along the 60 km coast of the De Hoop Nature Reserve (Figure 5.7). The De Hoop nature reserve is one of the largest on the Cape Coast and covers the southern tip of Africa, around approximately 340 square km and includes one the rarest limestone lowland Fynbos floral regions (Henshilwood *et al*., 2014). The Fynbos is within 200 meters of the cave and would allow access to a broad range of roots and tubers as a food source that would have been available at the time.

Excavations commenced in 2011 and revealed an intact MSA deposit 1.6m deep, with clear stratigraphic layers that would allow the accurate recording and recovery of materials. The first dates reveal MSA layers between the earliest anthropogenic level at 65.5 ± 4.8 ka to 59.4 ± 4.6 ka (by OSL) (Henshilwood *et al*., 2014). The material finds include lithics that are typical of the Howiesons Poort techno-complex found across many MSA sites and associated with complex behaviour (Brown *et al*., 2012; Lombard, 2008; Soriano *et al*., 2015; Wurz, 2008). A human left mandibular deciduous second molar was recovered from the site and dated between 64.6 ± 4.2 ka and 63.5 ± 4.7 ka (Henshilwood *et al*., 2014) confirming this as a modern human site. However, Klipdrift has some interesting faunal remains, which point to changes in subsistence strategies over time. There is a predominance of small mammals remains such as rock hyrax and tortoise, as well as ostrich eggshell, which is in line with other MSA sites such as Blombos and Klasies River. The faunal record, however, shows a variation in faunal remains, indicating possible changes in climate and vegetation (Henshilwood *et al*., 2014; Reynard *et al*., 2016a; Reynard *et al*., 2016b), with consequent adaptation in foraging strategies; this may be visible in the evidence of plant food exploitation, if any.

Again the profiles showed distinct and occasionally single use combustion features, with micromorphology samples taken (Figure 5.8). Klipdrift, both Cave and Shelter, therefore, was a good candidate site for this research, except that at the time of this project the levels were still at a more recent date level and not within the MSA 1 levels.

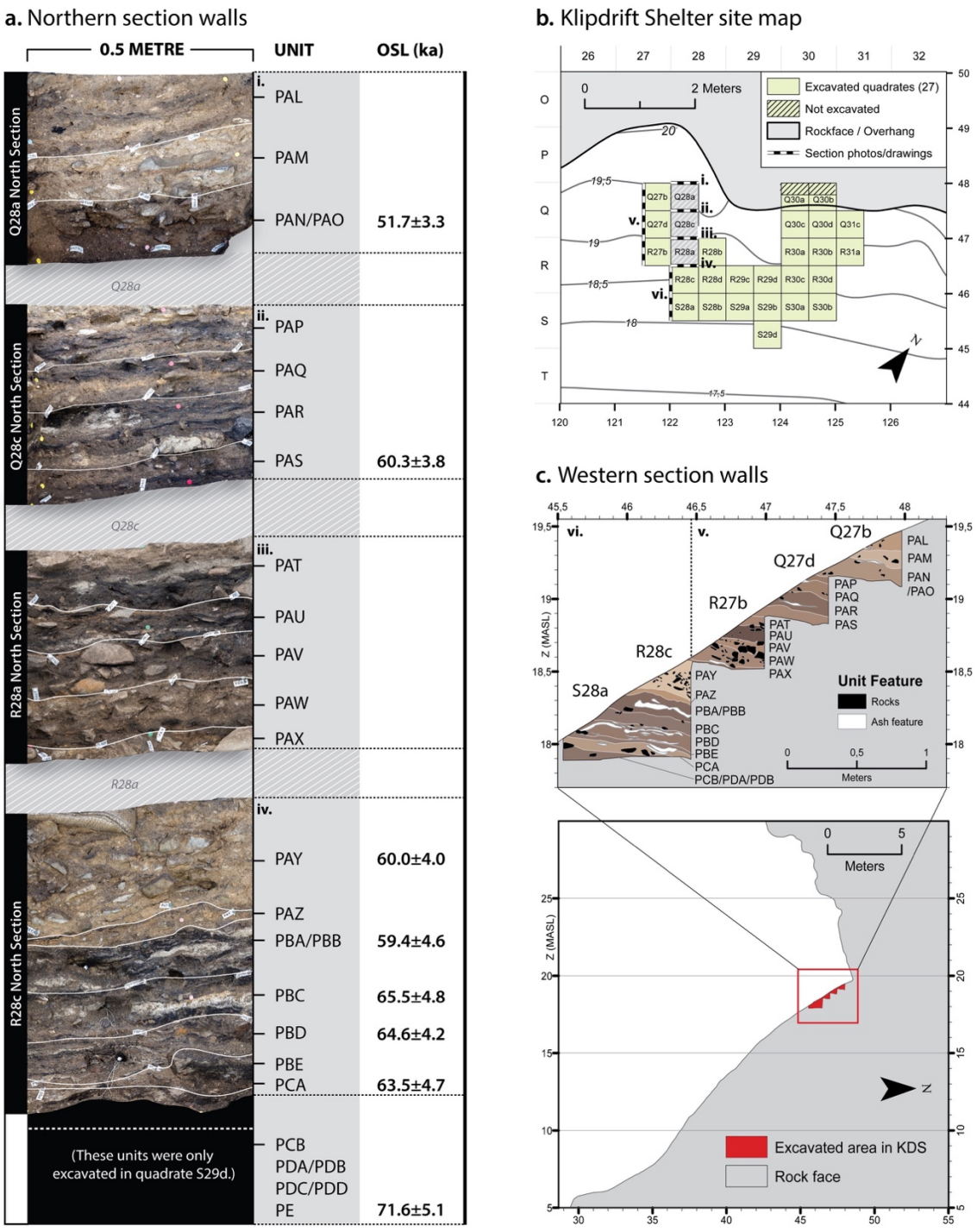


Figure 5.8: Stratigraphy and plan of the Klipdrift site from the 2011 excavations. (Image: Magnus Haaland)

5.3.4 Klasies River Cave Complex

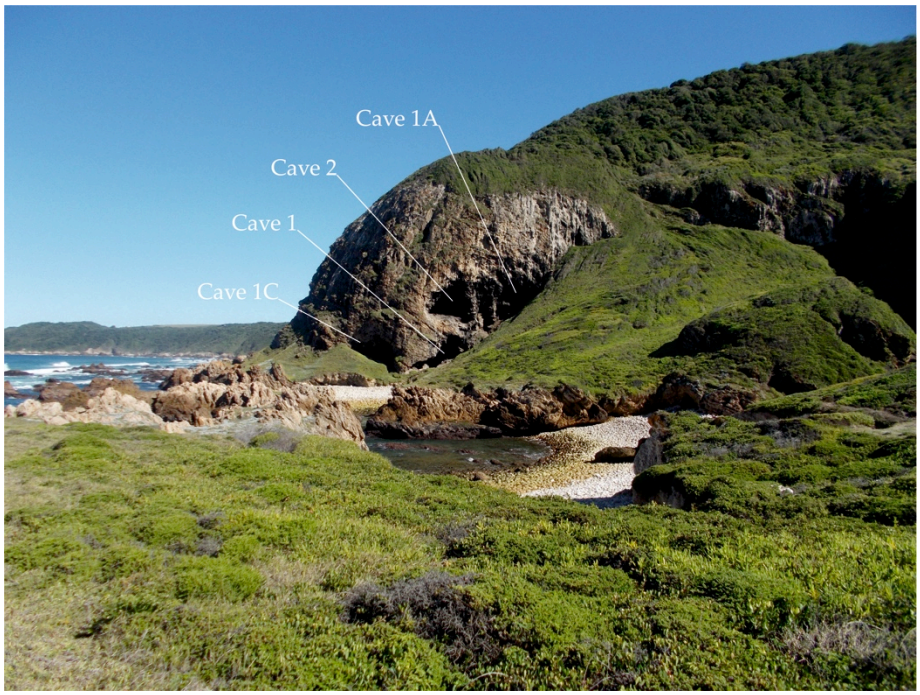


Figure 5.9: Klasies River Main Site, Eastern Cape. (Image: C. Larbey)

The Klasies River Main Cave Complex sits on the Tsitsikamma coast of the Eastern Cape Province, South Africa (34°6´29.17˝ S and 24°23´43.83˝E) (Figure 5.9), against the Tsitsikamma Mountains, which form part of the Cape Fold Mountains that run east to west from Port Elizabeth to near Cape Town (Carr *et al*., 2016) (See Figure 1.1).

The Klasies area lies between the Mediterranean climatic zone of the Western Cape and the subtropical zone of Natal, with year-round rain that has slightly heavier fall in the winter months (Singer and Wymer, 1982). The vegetation has been described officially as Fynbos (Deacon, 2001) but this only forms one element of a complex vegetation around the cave.

The main site (Figure 4.9) consists of three caves and two shelters at the base of a high cliff, Cave 1 (Main Cave), with levels from MSA I through to the LSA (the latter mostly vestigial), with Cave 1B (rockshelter), Cave 1C not visible and effectively under Cave 2, Cave 2 directly above, and Cave 1A (rockshelter), (Singer and Wymer, 1982).

One of the renowned early modern human occupation sites, Klasies River main site cave complex has a continuous anthropogenic depositional sequence from the earliest MSA sequences dated from Marine Isotope Stage (MIS) 5e ~120+ kya to the Howiesons Poort/MSA sequences dated 65-50 kya in Cave 2 and Cave 1A and provides a unique opportunity to observe early complex human behaviour and its adaptations over time. This behaviour has been seen in the change of techno-complexes over the duration of occupation, varying from the quartzite bladelets and elongated points of MSA1 to the small blades and backed geometric blades of Howiesons Poort that would have needed to be hafted together, using compound glues. The use of ochre, not locally available, to form these glues combined with evidence of the use of bone tools supports modern behaviour in the humans that routinely occupied this site (Wurz, 2008). The human remains are associated with abundant traces of occupation.

During the Middle Stone Age occupation of Klasies River the diets of hunter-gatherers included significant amounts of vertebrate and shell fish (Klein 1976; Van Pletzen 2000; Thackeray 1988). But the site has revealed the exploitation of large marine mammals, shell fish and terrestrial fauna as well as a range of ostrich eggshell and small mammals (Van Pletzen, 2000), and has a range of small independent hearths. The hunter-gatherer plant diet in the Pleistocene was anticipated by Hilary Deacon, who inferred that the carbonised remains around the hearths at Klasies River were evidence of plant foods and associated these with evidence of stored dried tubers found in LSA caves dated to around 30 ky (Deacon, 1993).

The stratigraphy of the site as well as Deacon's discussion on hearths suggests that the site falls well within the criteria for site selection (Deacon, 1993; Deacon and Geleijnse, 1988).

5.3.5 Sibudu Cave

Sibudu was visited and ultimately rejected as a potential research site. The following section describes why it was considered, what was found at the site and

why, ultimately, it was rejected.

Sibudu Cave is 40 km north of Durban, Kwazulu-Natal (Figure 5.10) and actually a large rockshelter, formed by erosion of Natal Group Sandstone on the steep, evergreen forested cliff overlooking the uThongathi River and its valley. The valley today is the only area that preserves any wild riparian vegetation as the thousands of hectares that surround Durban are now sugar plantation. The climate here is vastly more humid than that of the Cape coast.

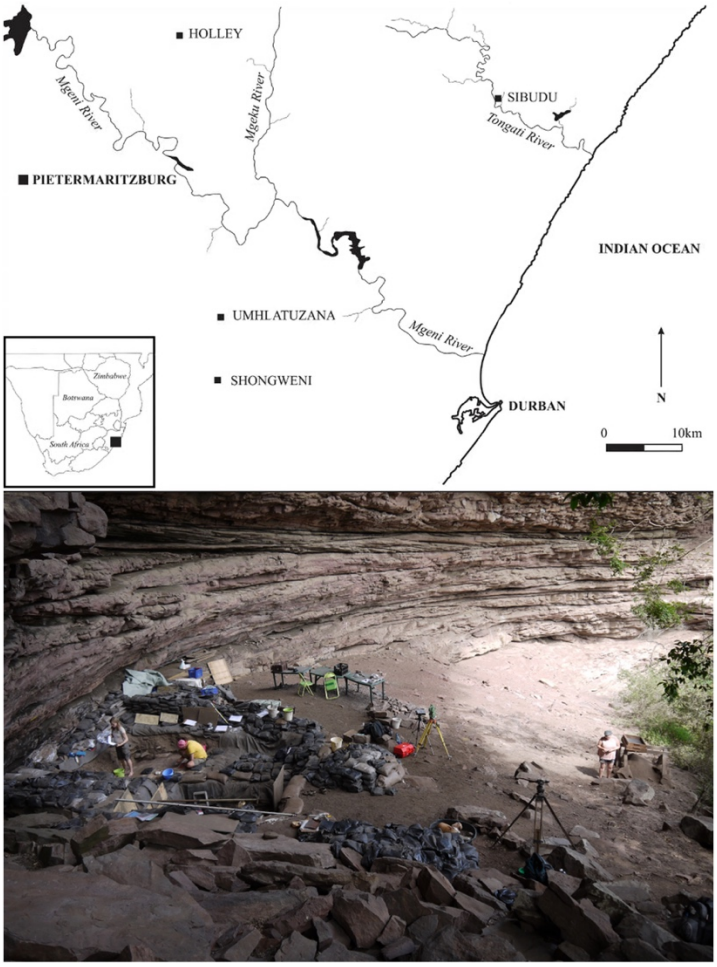


Figure 5.10: Sibudu Cave location. (Will *et al*., 2014).

The site has an MSA sequence that is largely anthropogenically derived, well-understood and dated from 77 – 26 kya (Goldberg *et al*., 2009). Sibudu is associated with lithic technologies known as Still Bay and Howiesons Poort, the

presence of which in certain levels have lent their names to these phases, *i.e*. Still Bay phases (72-71 kya), Howiesons Poort phase (before 61 kya), post Howiesons Poort (58-47 kya) and final MSA phases (36 kya).

Whilst no human remains have been found here, the site has been associated with early complex human behaviour, providing evidence of the earliest known bone needle (61 kya), compound glues for hafting (Backwell *et al*., 2008), some of the earliest evidence of bows and arrows (Lombard and Phillipson, 2015), and milk used as a paint binder in a milk-ochre mix (Villa *et al*., 2015). Sibudu has conducted archaeobotanical studies, which recovered both charred and mineralised seeds. Cyperaceae seeds and nutlets dominate the seed assemblage throughout the sequence at Sibudu, with the possibility that these sedge grasses were also used for food as well as bedding (Sievers, 2009). There are also long thick layers of burned plant material visible in the profile, that are considered to be bedding (Goldberg *et al*., 2009).

Overall, the possible evidence for tuber-use for food made Sibudu a promising context for this research. Although Sibudu did not offer the age depth of the coastal sites, an inland site in a different climate system would have formed a good comparison with the coastal sites.

The Field Visit to Sibudu

The vegetation around the cave site is tropical, riparian and dominated by monocot species with underground storage organs in the form of bulbs, rhizomes and swollen internodes. The site overlooks the uThongathi river that it was necessary to cross to reach the site (Figure 5.11).

Figure 5.11: The uThongathi River under Sibudu rockshelter, Kwazulu-Natal; crossing the river was the only access to Sibudu Cave. (Images: C. Larbey)

The Cyperaceae (*Cladium mariscus*) still grows by the river, under the cave (Figure 5.12) and has been identified in the MSA ash layers of Sibudu 65-77 kya (Sievers and Muthama Muasya, 2011) (see Figure 5.14).

Figure 5.12: *Cladium mariscus* still growing under Sibudu Cave (with weaver bird nests on the stems). .(Image: C. Larbey)

The excavation site is focussed on two trenches, the Eastern excavation and the

Deep Sounding (Figures 5.13 and 5.14) (Will *et al*., 2014), with excavation occurring on the east and north profile of the eastern excavation and on all four profiles of the Deep Sounding, this latter providing the oldest dated material so far.

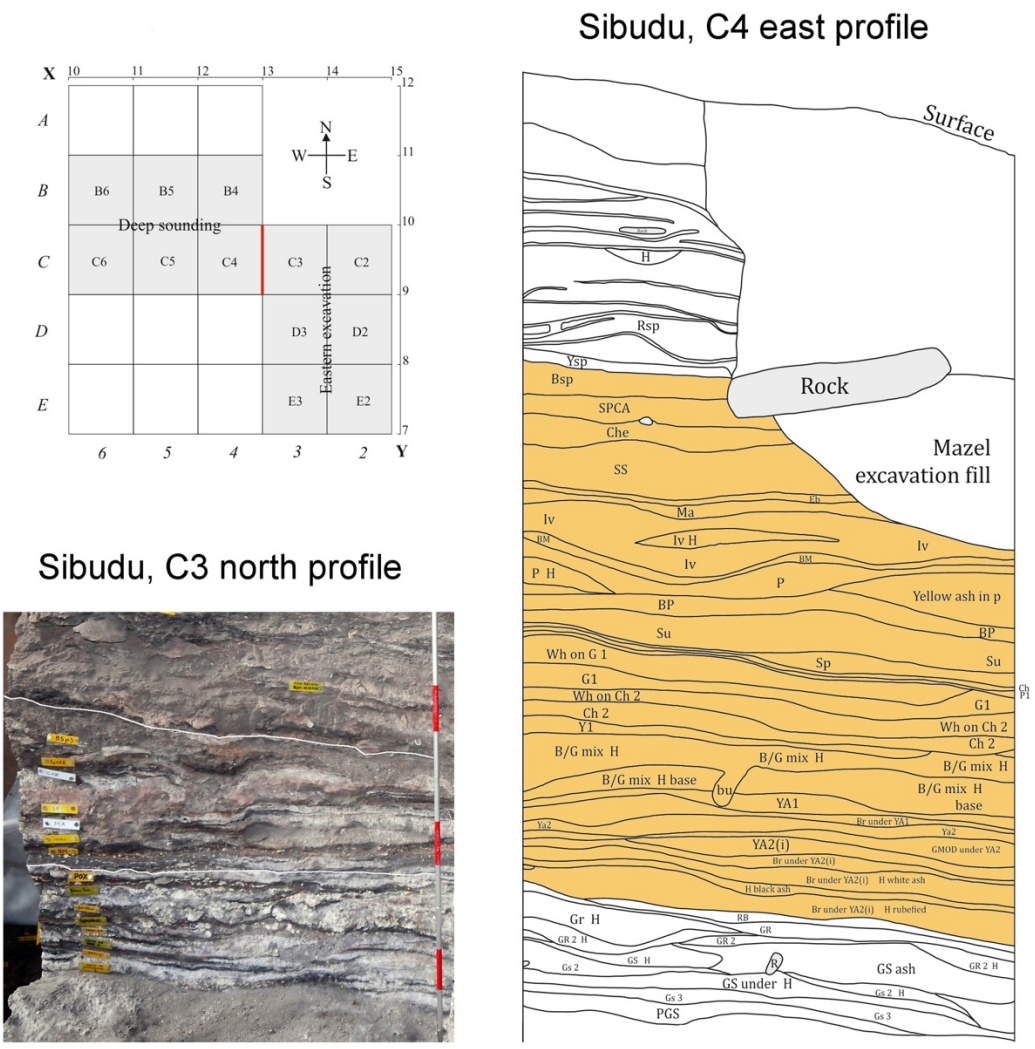


Figure 5.13: Sibudu Rockshelter north and east profiles of Eastern excavation. Images from Will *et al*. (2014).

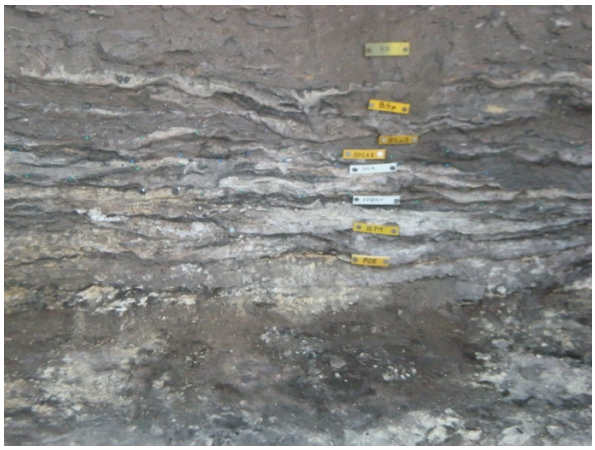


Figure 5.14: Sibudu east profile, upper section of D2 and E2 - ash layers visible are rich in the phytoliths of Cyperaceae interpreted as bedding. (Image: C. Larbey)

The issues that ultimately led to the rejection of this site lay within the site itself. Despite significant evidence of burning in the profiles, there was no evidence of undisturbed hearths in the section profile. This was confirmed by Prof. Chris Miller, the lead geoarchaeologist, on site (Miller, 2014, Pers. Comm.). Previous phytolith and FTIR research also suggests that the hearth structures are not preserved and that the structure of the ash deposits was destroyed shortly after deposition, either by trampling or by site maintenance (Schiegl *et al*., 2004).

5.4 The Final Choice of Sites and their Background

The sites chosen for this research were Blombos Cave in the western Cape and Klasies River in the Eastern Cape, each providing an example of different environmental systems and vegetation. Klipdrift Shelter would be sampled if discrete and well-dated hearth contexts could be found.

The global importance of Blombos and Klasies River cannot be over-estimated in human evolution and history. These sites have provided some of the earliest evidence of how humans lived, worked and ate in a rich and diverse environment – in different ways.

5.4.1 Blombos Cave

Blombos is a small cave (see Figure 6.8 Chapter 6) that would have accommodated one family/small group, but has produced early evidence of significant human cultural and technological transitions. The lithic technology associated with these levels is distinctive from the later Still Bay techno-complex. Predetermined blank shapes produced by core reduction that are rarely transformed by retouch are characteristic of this early techno-culture. This technology contrasts with later Still Bay and Howiesons Poort technologies that is defined by retouched and shaped tools (Douze *et al*., 2015).

The Still Bay techno-complex has foliate bi-facial points created by early use of pressure flaking on heat-treated silcrete raw material. This innovative production technique, whilst it allowed a greater degree of control to achieve finer and sharper points (Mourre *et al*., 2010; Villa *et al*., 2009), is seen at Blombos as a response to oscillating climate change and a need for flexibility between hunting and foraging strategies. The Still Bay phase of the sequence dates to between broadly 77- 70 kya. The innovation from this period is extensive and includes the cultural materials identified at Figure 5.5 above; early bone awls and projectiles have also been recovered from this phase (75-82 kya) (d'Errico *et al*., 2015; Henshilwood *et al*., 2001a).

The 'tool-box' of Blombos supported a range of subsistence activities. The subsistence strategy seen in the lower MSA levels (101-85 kya) indicates a reliance on complex foraging. Here, the term 'complex foraging' is used to mean a major economic activity that included shell fish collection, small mammal snaring, the collection of eggs, tortoises and washed-up dead seals, dolphins and penguins, as well as plant foots. Some of these activities, the collection of ostrich eggs for example, may have included the whole group and required organisation. Vertebrate and mollusc evidence for all these activities has been recovered from Blombos cave and shows that marine and terrestrial resources were fully exploited season by season, particularly tortoises and ostrich eggs (Henshilwood *et al*., 2001b).

Vertebrate remains from the Still Bay phase reflect a shift in emphasis to increased reliance on hunting of larger, higher return ungulates, supported by the evidence of an increase in the number of Still Bay points recovered from this sequence.

However, evidence also suggests a continued reliance on foraging with an increased reliance on tortoises (Thompson and Henshilwood, 2014). The importance of tortoises (mostly *Chersina angulata*) as a food resource has been explored by Thompson and Henshilwood (2014). All major MSA sites along the Cape coast of South Africa have recovered evidence of extensive exploitation of this foraged animal food. The number of tortoise remains increase in a direct correlation with the retreat of the shoreline and marine resources become more difficult to access during the c. 75 thousand years to the Still Bay phase. In their paper, however, Thompston and Henshilwood (2014) state that over time, the people visiting Blombos Cave return to hunting large ungulates. The hunting of large ungulates appears to counter both the Optimal Foraging and Niche Construction Theories (Hillman and Wollstonecroft, 2016). Why would hunter-gatherers hunt larger ungulates so extensively, particularly as they are just large 'parcels' of protein, offering no fat and only some micronutrients, when such a large source of foraged food that combines protein, fat and micro-nutrients is more easily foraged? Plants were not considered in the equation because this PhD research represents the first research into plant food for this region. However, in an experimental research project that assessed plant underground storage organs as a possible year-round food resource, Singels *et al*. (2016) concluded that these would have been easily available all year and would have played a critical role in the diet of early humans.

If the hunter-gatherers of the Cape coast MSA were solely economically, rather than socially motivated, then complex foraging rather than hunting would have been an easy source of both macro and micro nutrients. The implication of this is that hunting had a strong social motivation yet foraging was the main economic activity. This model has parallels in Australian aborigine hunting and foraging strategies (Gould, 1986; Hamilton, 1975; Jones, 1980).

The occupations at Blombos appear to coincide with high sea levels. The eustatic sea levels along the Cape coast are a significant influence on frequency of occupancies of all coastal MSA sites and the foraging and hunting strategies employed during the corresponding cycles of hot/dry and cold/wet climates (Simon *et al*., 2016). Shellfish form a significant element of the complex foraging (Langejans *et al*., 2012; Thompson and Henshilwood, 2014), in line with other key MSA sites on the Cape coast: Klasies River, Ysterfontein and Pinnacle Point (Klein *et al*., 2004; Nelson-Viljoen and Kyriacou, 2016; Thackeray, 1988). The complex foraging persists in variable degrees throughout the MSA sequence – it seems reasonable that the level of cognition and innovation seen at Blombos in the understanding of long processing sequences, seasonality, and the knowledge of various biomes and animal behaviour patterns, may also be applied to plants and plant food foraging.

5.4.2 Klasies River

Klasies River provides the opportunity to see early human occupation on a larger scale and in different social activity; not the shell beads of Blombos but the potential differences in co-operative hunting, with megafauna such as elephant, rhino and extinct giant buffalo being hunted and cooked together in large charcoal hearths, excavated in 2015 (see Figure 6.5 in Chapter 6). The MIS I phase offers the earliest evidence of the exploitation of marine resources such as shellfish, dolphin and marine mammals. Parts of Klasies are characterized by shellfish middens but these are also a common feature of most other coastal MSA sites such as Ysterfontein 1 (Wurz, 2012). The mosaic of terrestrial biomes probably meant that hunter-gatherers could have subsisted on a diet of 100% of whatever they chose: meat, shellfish or plant foods, evidenced by the vertebrate and marine resource remains in the cave and the abundant roots and tubers resource in the regions around the cave. But they appear to have optimized each resource on a seasonal basis, including roots and tubers.

The current narrative for the Howiesons Poort phase at Klasies River (70-60 kya) suggests there was an increased focus on foraging during this cold MIS 4 phase, with more small bovids and mammals such as grysbok and rock hyrax that ethnographically are snared or trapped (Marean *et al*., 2014). Figure 5.15 compares trends between the early MSA and the Howiesons Poort/Still Bay phases.

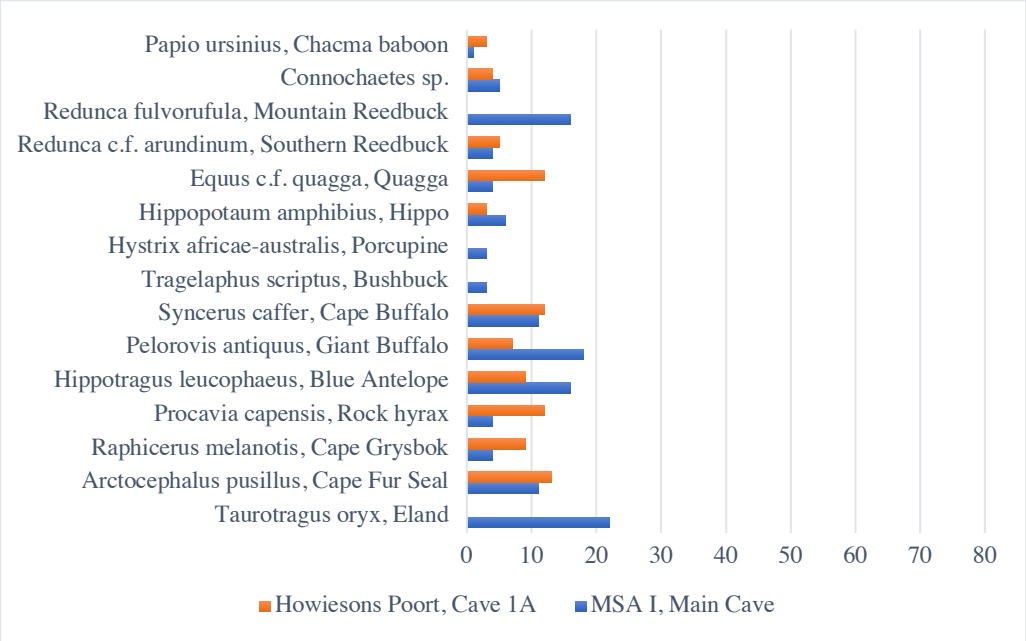


Figure 5.15: Comparison of top fifteen minimum number of individual (totals) between MSA I phase, Main Cave and Howiesons Poort phase Cave 1A. Data from Klein (1976: 77).

The trend in Figure 5.15 shows the mammals that prefer wooded environments are missing in the Howiesons Poort phase, such as mountain reedbuck (*Redunca fulvorufula*), bushbuck (*Tragelaphus scriptus*) and porcupine (*Hystrix africae-australis*). This correlates with the THI (Taxonomic Habitat Index) from the micro-mammal analysis from Klasies River (Hillestad Nel *et al*., 2018). The overall numbers of animals for both phases, especially as all elements were not present, are small over these time spans and it seems more likely that hunting supplemented by foraging was the main subsistence strategy.

The site also includes small hearths, c. 30 cm diameter in all phases, that are ashy, with small food remains: small animal bones, shell fish and unidentified plant

remains that Deacon ascribes to nuclear families (Deacon, 1995). How this 'big hearths with big kills and little hearths with small food' concept reflects social patterns is difficult to know. Very little interpretation of these hearths has been offered. The big hearth appears to reflect likely co-operative hunting during MSA 1 of mega fauna on the coastal plains. The small hearths, however, because there is continuity in appearance and content through the LSA and because of their similarity to those of the modern San, among whom they believe the hearth belongs to the woman, have been connected to nuclear families (Deacon, 1995). How many people visited this site at one visit is unknown. Similarly, it is unknown whether the site was only used in bad weather. This is an area for future research, but the foraged nature of the contents of the small hearths and the big game content of the big hearths suggests one group with two distinct social subsistence strategies.

During this complex picture of human response to climate change there are two key points. Firstly, there are few plant extinctions during this period and this is one of the reasons for such great plant diversity today in the Greater Cape Floristic Region (Cowling and Lombard, 2002; Ellis *et al*., 2014). Secondly, the THI of the vertebrate species from both Klasies River and Blombos suggests that the botanical micro-biomes persisted throughout the MSA 2 stage, although there are clearly changes in the way they were constituted (Marean *et al*., 2014).

5.5 Aim of Fieldwork

The aim of this research was to identify, if possible, hearth features where roots and tubers could have been cooked as food in early modern human contexts.

There were four key issues related to this aim:

- To gain access to the earliest possible, yet well-recorded, early modern human occupation sites.
- To obtain permission to take samples from these rare sites back to the UK.

- To choose methods for extraction that would be sufficiently robust to be able to distinguish charred fragments of roots and tubers (parenchyma) but also to distinguish between no evidence of roasting roots and tubers and no preserved evidence of roasting roots and tubers.
- To identify hearths within deep time contexts. Many of the candidate archaeological sites have been already extensively excavated and not many undisturbed hearths remain.

5.6 Considerations for Fieldwork and Analysis

5.6.1 Palaeoenvironment of the Cape Coast

The palaeoenvironmental data for the Cape include both large scale, Cape-wide data and smaller more localised studies. The large scale climate research studied sea currents, bathymetrics, potential weather systems, pollen and sediment cores. The southwestern Cape occupies a transition zone between the temperate (winter) and subtropical (summer) moisture-bearing circulation climate systems (Quick *et al*., 2016). These studies concluded that over the last 150 thousand years the Cape climate remained equable with only moderate changes such as warmer and wetter conditions during the interstadials (between glacial stadials). The peak inter-glacial occurred c. 123 kya (MIS 5e), with a glacial peak around 109 kya (MIS 5d) followed by conditions that were cooler and drier during the glacial stadials, 98-55 kya (MIS 5c-MIS 3), and the LGM 25-30 kya (MIS 2) (Carr *et al*., 2016; Chase and Meadows, 2007; Chase *et al*., 2015; Compton, 2011; Quick *et al*., 2016; Roberts *et al*., 2016; Ziegler *et al*., 2013). There were two key elements that impacted the Cape coast: the first comprised the changes in the coastal landscape dynamics in certain places along the coast caused by glacial stadial phases, and the second was wildfire, probably caused by lightning strikes that had a significant evolutionary impact on the Fynbos vegetation.

Drops in sea levels would have exposed coastal plains. The plains would have been home to the elephant, rhinoceros, wildebeest and buffalo whose remains are found in the MSA sites along the Cape Coast (Klein, 1976; Thompson and Henshilwood, 2011; Van Pletzen, 2000). Interglacials would have brought the

coastline much closer to the cave sites and offered a rich marine resource of shell fish, washed-up sea mammals and penguins and shallow marine foraging opportunities seen at all MSA sites (Avery *et al*., 2008; Henshilwood *et al*., 2001b; Klein *et al*., 2004; Marean and Binford, 1986; Thackeray, 1988; Wurz, 2012). These coastal changes included pulses of coastal dune activity (Figure 5.16), which certainly influenced occupation of the cave sites at Blombos and Klasies River and may have affected resource availability. (Carr *et al*., 2010; Carr *et al*., 2016; van Andel, 1989; Will *et al*., 2013).

Figure 5.16: Fossil sand dune below Blombos Cave, Western Cape coast, South Africa, with Dr. Simon Armitage, Royal Holloway, University of London for scale. This dune is estimated to be 70-80 kya (Armitage, 2013, Pers. Comm.). (Image: C. Larbey)

The accumulation of dune sand would account for the abandonment of the main cave and the occupation of the higher Cave 1A and Cave 2 during MSA II and the Howiesons Poort Phase (Butzer, 1978; Butzer, 1982). This also affects preservation conditions in the cave.

There is, however, an east-west divide along the Cape coast, with the Western cape drier than the Eastern zone (Altwegg *et al*., 2014). The Eastern coastal zone is significantly more prone to lightning strikes at 0.42 ± 0.09 lightning strikes per square kilometre mean zone compared to the Western coastal zone that has 0.16 ± 0.16 strikes per square kilometre (Kraaij and van Wilgen, 2014). The Fynbos vegetation is the result of climate stability and is adapted to fire, with a high

proportion of serotinous (plants whose seeding is triggered by fire) and obligate seeding (plants that re-seed after a fire) species (Altwegg *et al*., 2014; Pausas and Keeley, 2014). Different geologies along the coast mediated more localised climate differences and these have been established on a site by site basis by the analysis of proxies that included mammal fauna (Blombos, Klasies River), molluscs (Klasies River), carbon and oxygen stable isotopes of ostrich egg shell (Blombos), and speleothems (Pinnacle Point) (Bar-Matthews *et al*., 2010; Klein, 1976; Loftus *et al*., 2017; Roberts *et al*., 2016).

Table 5.1: Summary of palaeoenvironments at Blombos Cave and Klasies River Main Sites during the MSA. after Marean *et al*. (2014).

Site	Age (kya)	Palaeoenvironmental Summary
Blombos Cave	110-70	Large mammal fauna, large numbers of seal, indicating the coast is near. Significant numbers of grysbok and steenbok, indicating the presence of Fynbos. Significant numbers of southern reedbuck and consistent but low numbers of hippo indicate the close presence of fresh water. Low but consistent numbers of alcelaphines attest grasslands.
Klasies River	110-50	Large mammal fauna, seals indicating coast is near, with substantial number of extinct long-horned buffalo, blue antelope and smaller numbers of alcelaphines suggesting open habitat grassy environments. Bushbuck and greater kudu indicate thicket, and substantial numbers of grysbok show the presence of Fynbos. Low but consistent frequencies of southern reedbuck and hippo attest the presence of fresh water.

The climate and environment around Blombos Cave during MSA 1 suggest a marine and terrestrial resource rich environment, with the lack of forest and thicket suggesting a drier environment than that of Klasies River. Klasies appears to have a mosaic environment with access to plains, savanna, thicket, fresh water and possibly even Afro-forest (Table 5.1).

5.6.2 Reference Materials

The relative stability of the palaeoenvironment is an important factor in the lack of extinctions and the consequent great diversity of the Cape Floristic Region (CFR) (Ellis *et al*., 2014). The result of this is that a large percentage of the indigenous families and species in the CFR today would have existed during the MSA, meaning that the collection of a modern reference collection of roots, rhizomes, tubers, corms and bulbs is viable. There is no existing parenchyma reference collection for the Cape coast, South Africa.

It would be necessary to find a botanist with the necessary knowledge and permits to identify plants and take samples to create a modern parenchyma reference collection. The samples would be mapped to specific micro-biomes, photographed, dried and then burned according to a protocol set up by Hather, and SEM micrographs would be taken of the species collected, focussing on morphological characteristics and parenchyma cell shapes (Hather, 2000).

5.6.3 Preservation Conditions

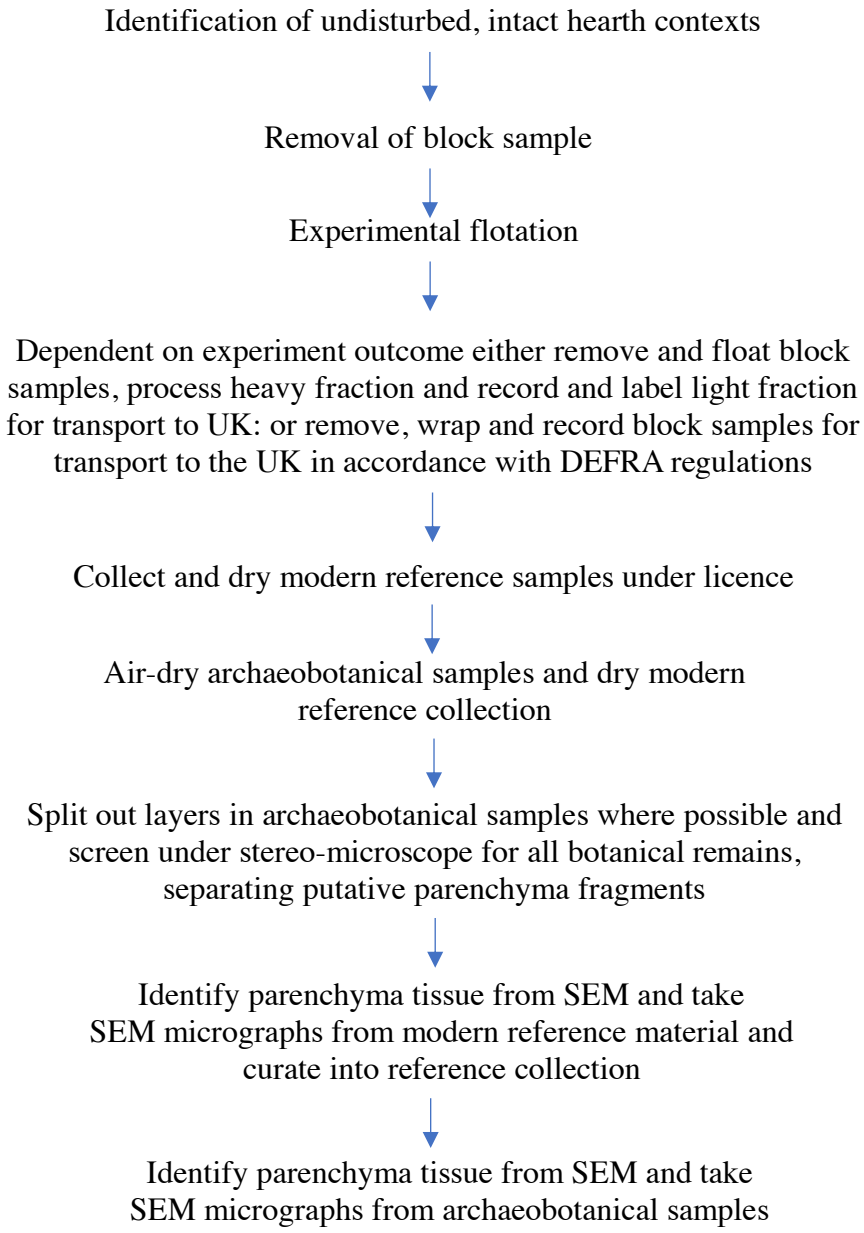
Preservation conditions would determine the methods of both sample collection and ultimately of handling and methods of analysis. The preservation conditions would have to be assessed in the field, as wet/dry conditions within the cave would have had a detrimental effect on the charred botanical remains. Both Blombos Cave and Klasies River have a basal layer of Table Mountain Group sandstone. Quartzite, with slate and shale and Bokkeveld metashales that form part of the landscape around the Klasies River main site and yet the periodic incursions of sand dunes provide an alkaline environment (Wurz *et al*., 2018). Humified layers of decomposed plant material, possibly bedding or fuel, also affect the pH of the caves and rockshelters.

Blombos Cave is in ancient wave-cut cliff, formed in calcified sediments of the Bredasdorp Group. The generally alkaline environment, created through periodic incursions of sand, is conducive to the preservation of bone and shell, but with varying pH levels nearer the cave walls, which may be due to the decomposition (humification) of plant materials (possibly bedding/fuel) and/or discarded plant remains (Henshilwood *et al*., 2001b).

5.7 Planned Methodology

The planned outline method in the field involved the following Table 5.2:

Table 5.2: Planned methodology and work flow from field to laboratory



The archaeobotanical samples would be taken in blocks from the context sections and not from trowelled fill. Whether the block samples were then floated as per the method in Pearsall (Pearsall, 2015) would depend on the preservation conditions and experiments would take place on-site to ascertain whether samples could be

floated or had to be taken back to the UK to be micro-excavated under the microscope.

In the laboratory, the samples would be screened for botanical remains under a stereo-microscope. Putative charred parenchyma tissue would be analysed using a Hitachi TM 3000 environmental scanning electron microscope (SEM). SEM micrographs would be taken for each fragment, particularly parenchymous tissue.

5.8 Conclusion

With the choice of method selected in Chapter 3, this research design has identified a plan that would deliver data that would answer the research question. This chapter identified the reasons for selecting *Homo sapiens* for this research; the significant gap in the current understanding of the plant diet of early humans, despite genetic and biological research suggesting that humans are uniquely adapted to a starch diet. The process of identifying and selecting appropriate sites was detailed and the balance of this chapter offered the pre-planning for the field and for equipment needed in the laboratory. This research design also anticipated issues of taphonomic resolution and preservation, which could only be managed once these were known in the field.

Chapter 6

Method

6.1 Introduction

The research design set out in Chapter 5 provided the framework for the method used. As research progressed, the method was improved by a better depth of understanding of the sequences and hearths and the developments offered new opportunities for sampling strategies and methods.

The first fieldwork season for this research took place at Blombos Cave, and this site informed the subsequent sampling strategies employed at Klasies River. The prior identification of undisturbed hearths by Dr. Susan Mentzer at Klasies River and the subsequent communication of unpublished analysis contributed to an exceptional understanding of the micro-contexts of the hearths from which the botanical samples came.

The following sections describe in detail the process of identifying the hearths, the sampling strategies, the laboratory processes employed that identified edible plant remains, and finally how those plant remains have been identified, categorised and curated.

6.2 Hearth Identification

The aim of the fieldwork was to take samples from which to recover and identify starchy plant remains that had been introduced to the site by humans and subsequently processed by cooking; aims most likely to be met by sampling hearths. As outlined in Chapter 5, the identification of intact hearths was a key criterion for choosing a sampling context. For example, one of the main factors for the rejection of the site of Sibudu was the extensive evidence of both trampling and site maintenance activities, specifically the clearing and dumping of hearth

ash. These depositional characteristics were both visible in section and had previously been identified by micromorphology analysis (Goldberg *et al.*, 2009; Wadley and Jacobs, 2006). The identification of intact hearths with the naked eye is more difficult.

The simplest form of hearth, and the one with which archaeologists are most familiar in cross-section, is the broadly circular, lenticular-shaped, three layered hearth, consisting of a heat-altered substrate, overlain by a first layer of charred material and a second layer of ashes (Meignen *et al.*, 2002; Mentzer, 2012). Hearths, or combustion features/structures, however, can differ in morphology and composition from that simplest form (Figure 6.1) (Mentzer, 2012).

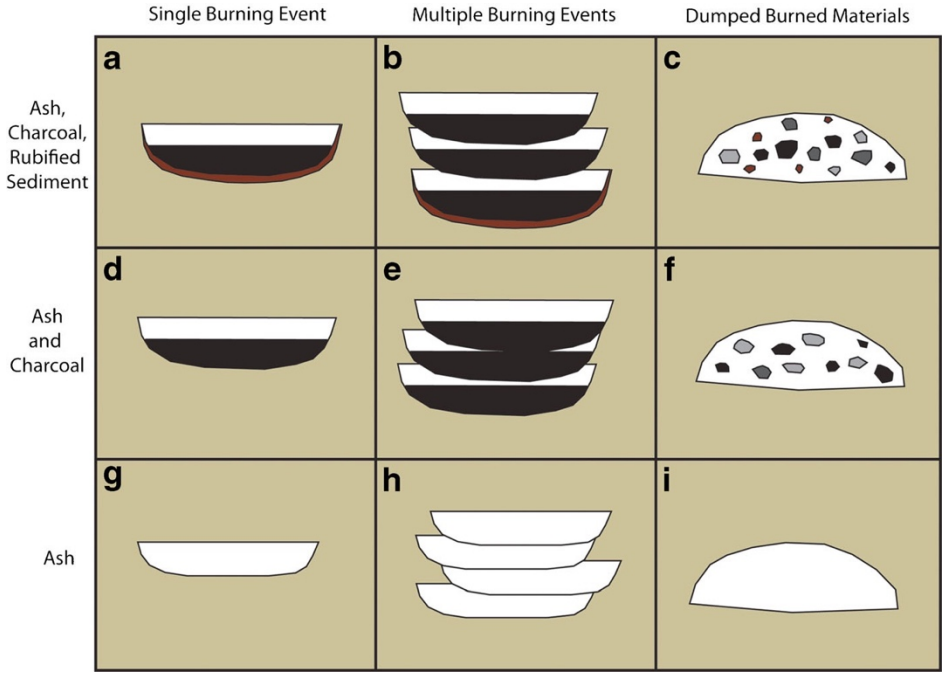


Figure 6.1: Varying hearth morphologies and structures encountered in archaeological sites (from (Mentzer, 2012).

Wood charcoal is created by fires that burn at a low temperature (lower than 1000°C), and that do not burn out completely. In contrast, many non-woody plants, such as grasses and sedges that might be burned bedding or mats, do not produce charcoal (Mentzer, 2012). Non-woody plants are composed of different tissues that carbonise at different rates and often burn with hotter, more intense fires, leaving clear pale grey ash layers (Mentzer, 2012). Consequently, the hearth may be formed of pure ash or in the case of multiple use, may include charred

material. The MSA hearths at Sibudu Cave, KwaZulu-Natal, South Africa, exhibit these characteristics (Wadley and Jacobs, 2006).

"Hearths are discernible in the MSA layers as flat, irregularly circular patches of ash. The hearths are never surrounded by stones and they only rarely have convex bases. Some hearths have a chestnut-coloured base that results from the burning of deposits at the base of the fire. The centre of such hearths is black, sometimes with concentrations of charcoal, and the upper crust of the hearths contains off-white or yellow ash. Palimpsests of hearths comprise inter-fingered black, chestnut and white or yellow lenses, but individual burning episodes cannot be distinguished …" (Wadley and Jacobs, 2006: 8).

As described in the previous chapter, it was important to understand the stratigraphic relationship between the hearth substrates that may be the debris from previous occupation surfaces or linked with a previous combustion event and the contents of the burning event. Micromorphology, micro-FTIR (FTIR = Fourier transform infrared spectrometry) and organic petrology analyses have been increasingly employed to define these micro-contexts (Mallol *et al*., 2013b). These techniques enable archaeologists to differentiate single from multiple use hearths, ash dumps, occupation layers from substrate, and burned food remains from mineralised remains. Organic petrology analysis is carried out on micromorphology samples, using reflected white and blue light, and measurement of fluorescence of organic particles (macerals) (Miller *et al*., 2016). Analysis of the form, property and reflectance of the macerals can help to identify the origin of the organic material, and assess its degree of humification and/or charring (Miller *et al*., 2016: 80). In the case of Klasies River, this analysis was able to identify burned fat particles associated with vertebrate bone and plant remains, which are described below.

6.2.1 Hearth Features at Blombos Cave

Identifying hearths at Blombos appeared relatively straight-forward. Several hearths were visible in the section (Figure 6.2).

Figure 6.2: Two hearths in section at Blombos Cave, at the base of CGAC level – 85-90 kya.(Images: C. Larbey)

The hearth in the left image of Figure 6.2 exhibits classic lenticular shaping, whereas the hearth on the right is of the completely flat type described by Wadley at Sibudu (Wadley and Jacobs, 2006). These hearths, however, were not intact and neither hearth had an ash layer.

The Blombos Cave micromorphology sampling started in the same fieldwork season as the botanical samples were taken for Blombos Cave. The results were unavailable, therefore, to identify potential intact hearths prior to excavation. The subsequent analysis of the micromorphology thin sections tracked hearths through the density and colour of glauconite grains, a mineral that systematically changes colour on a scale at temperatures above 400 °C (Haaland *et al*., 2017). There is currently no evidence of intact hearths.

6.2.2 Hearth Features at Klasies River Main Site

The Klasies River Main site is significantly larger and more complex than Blombos Cave. Blombos is a single cave with one sequence, whereas the Klasies River site sequence includes several caves (Cave 1, Cave 1A, 1B, 1C and Cave 2); MSA I and MSA II in Cave 1 and rockshelter Cave 1B; MSA II in Cave 1C; Howiesons Poort and MSA II and III in rockshelter Cave 1A and Cave 2; each with many occupation levels (Figure 6.3). The hearths in the MSA deposits at Klasies River main site have been described by Deacon as "…discrete circular hearths set in carbonised partings or haloes of brown (humified organic) soil and discrete middens of bone and shell food waste." (Deacon, 1995: 125). A further

aim developed for this research was, therefore, to sample later MSA levels if possible to make both inter and intra site comparisons between the hearths.

Figure 6.3: Klasies River Main Site (Dr. Alice Novello in foreground for perspective). (Image: C. Larbey)

The challenge at Klasies River was to distinguish undisturbed hearth features from the humified layers of black/brown organic material which appear to represent occupation layers and are characterized by trampled charred remains and mineral staining. There have been no layers of bedding identified here as at Sibudu (Goldberg *et al*., 2009), although there are significant areas of humified organic remains that may have been bedding. Lack of clearly discernible bedding could be a function of trampling, the full extent of which was identified only by micromorphology analysis (Mentzer, 2016, Pers. Comm.). As an example, Figure 6.4 shows what appear to the naked eye to be 'burned' layers from the Howiesons Poort phase of Cave 1A, but which were identified by micromorphological analyses as layers of humified organic remains and occupation layers.

Figure 6.4: Cave 1A, Howiesons Poort Phase, 70-50 kya showing multiple 'burned' layers and ash hearth in red box. (Adapted image from: S. Mentzer)

At Klasies River main site, undisturbed hearths were characterised by intact layers of ash as under 'F50' in Figure 6.4, with no charred base layer. These hearths appear similar to the small fires described by Deacon (Deacon, 1995), but are set on unprepared surfaces of trampled debris of burned and unburned material. Micromorphology analysis and micro-FTIR measurements on bone fragments from the Cave 1 hearth debris layer indicate that they were not exposed to any heat or were burned at very low temperatures. The single large bone fragment within the lower hearth had been heated to 700°C or above. The micro-FTIR analysis of the debris layer beneath the Howiesons Poort hearth indicates the presence of aragonite shells within the upper portions of the debris layers, suggesting that indirect heating of the hearth substrate never exceeded 550°C. Yet the ash layer of the hearth contained shell fragments that exhibit petrographic characteristics consistent with burning and are all composed of calcite, indicating temperatures well above 550°C. (Mentzer, 2016, Pers. Comm.). In the case of both hearths, therefore, the micromorphology and micro-FTIR results indicate that the charred layer beneath the hearths in each case was part of the debris layer on which the

hearth was laid, and not part of the first combustion event. This was particularly relevant for understanding the context of the plant remains.

The main excavation focus during the 2015 fieldwork season was the MSA 1 phases of the southern end of the Witness Baulk, a large unexcavated spit running the length of Cave 1 (see Figure 6.10 for site plan). This area was selected because it exhibited evidence of intensive occupation (Figure 6.5), with considerable evidence of burning throughout all levels, including high densities of charcoal.

Figure 6.5: Excavation of the MSA 1 phases of the Witness Baulk, Klasies River, South Africa 2015. Note the density of occupation evidence, the intricacies of which necessitated excavation with a kebab stick. (Image: C. Larbey)

6.2.3 Taphonomic Control

The identification of hearths from previous micromorphology thin section analysis provided an unambiguous context from which to sample. Samples taken from these contexts were classified as Class A samples according to Hubbard and Clapham (1992). To take botanical samples from the same hearths that also have a detailed geoarchaeological analyses has a further advantage. The suite of thin section, micro-FTIR and organic petrology analyses carried out by Dr Mentzer on the samples from Klasies River allowed a detailed understanding of the stratigraphic relationship of the other potential food materials in the hearth and the substrate. The substrates in every hearth sampled from Klasies River were debris

layers and were not contemporary with the hearth deposit. The artefacts in these debris layers included burned and unburned bone and burned and unburned marine mollusc shell. Micro-FTIR analyses were able to determine temperatures reached in certain areas of the hearth. Organic petrology analysis identified black opaque particles with no cell structure as with charcoal but with a homogenous texture that included bubbles or vesicles that suggested they were originally fluid and had hardened after the release of volatile gases. These particles are consistent with char derived from the burning of flesh, bone and/or animal fat (hence fat-derived char) (Mentzer, 2016, Pers. Comm.; Villagran *et al*., 2013) and demonstrate that other foodstuffs were being cooked and were contemporary with the plant remains recovered from these layers.

6.3 Preservation and Flotation Experiment: Blombos Cave

Trowelled sediment at Blombos is dry sieved in a 4mm mesh and very little charcoal is recovered in this process. During the excavation at Blombos, the charcoal in the sediment was moist, giving it a buttery texture that smeared when the trowel scrapped across it. The charcoal fragments in this moist condition were also extremely fragile to handle. Two experiments were run to test whether flotation would be a viable method for the collection of botanical remains. Samples were collected from a hearth that became apparent during excavation and these were used for the experiment.

Experiment 1

The Objective: to float sediment known to contain charcoal fragments and to observe the outcome.

The Method: A 250 ml block sample of archaeological hearth sediment in which charcoal fragments were visible (Figure 6.6 (left)) was floated in a small bucket with fresh water.

The Outcome: These samples were placed in water in a small bucket flotation. No charred plant remains floated to the surface and the experiment produced just muddy water (Figure 6.6 (right)).

Figure 6.6: Flotation Experiment 1: (Left) a 250 ml block of sediment from CFD G7a (76.7±4.8 kya), Blombos Cave; (right) result of flotation. (Images: C. Larbey)

Experiment 2

The Objective: a) To observe clearly the reaction of archaeological charcoal in both fresh water and seawater, without surrounding sediment, which muddies the water. b) To observe any difference between fresh and seawater.

The Method: Two fragments of dried archaeological charcoal from Blombos Cave and two fragments of modern charcoal of equal size were floated. One fragment each of archaeological and modern charcoal was floated in a jug of fresh water and one fragment of each in a jug of filtered seawater.

The Result: The modern charcoal floated in both fresh and seawater. Both fragments of archaeological charcoal 'exploded' on entry into the water and sank to the bottom (Figure 6.7). The fact that there is no difference between fresh and seawater is important to note for future flotation methods, where seawater may be the only source of water.

The outcome of Experiment 2 is important for archaeobotanists who have long been concerned about the impact of salt water on charred plant remains collected by flotation.

Figure 6.7: Flotation Experiment 2: Floating modern charcoal fragment and archaeological fragment 'exploded' and sunk to the bottom of fresh water. (Image: C. Larbey)

It was clear that flotation was not an option and block sediment samples would have to be taken back to the UK for micro-excavation. Subsequent micromorphological analysis showed poor preservation of plant remains due to a high degree of peri-mineralisation in the plant tissue (Mentzer, 2016, Pers. Comm.) . This would be coherent with the disintegration of the fragments in water in both flotation experiments.

6.4 Sampling Strategy and Collection

In both Blombos and Klasies River, most samples were taken through identified hearths, and where possible at the edge of a hearth. Samples were also taken from selectively adjacent positions, off hearth.

6.4.1 Blombos Cave

The excavation season of 2013 was focussed on the south section, quadrants F7b, G7a, G7b, H7a and H7b (Figure 6.8).

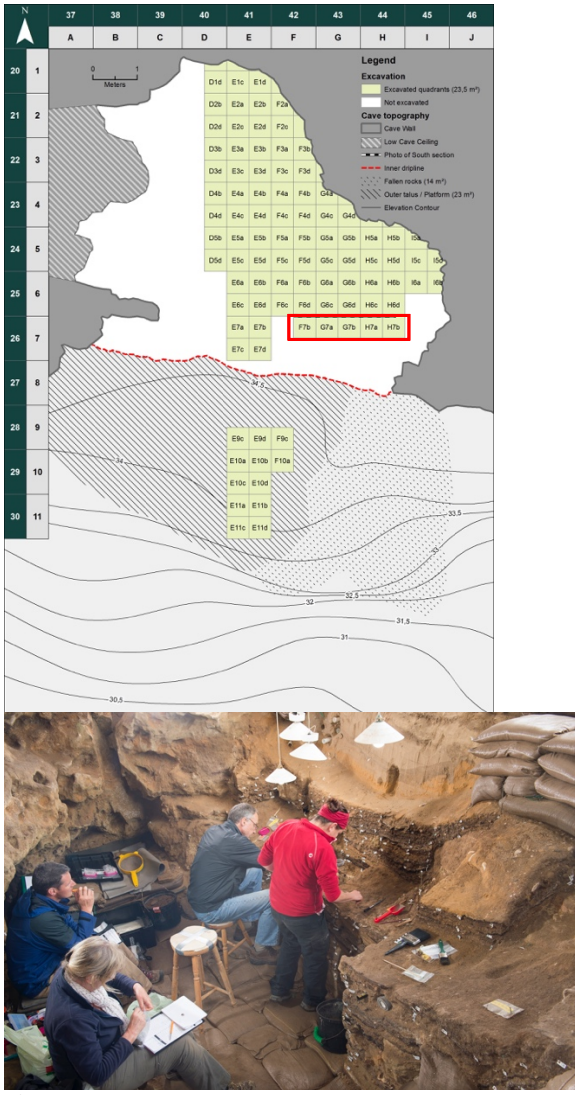


Figure 6.8: Above: Blombos Cave site plan showing excavated areas and south section excavated in 2013 – outlined with red box. (Image from (Haaland *et al*., 2017). Below: Prof. Chris Henshilwood and Dr. Karen van Niekirk (in red) excavating south section of Blombos Cave with author and Dr. Rian Rifkin recording behind. (Image: M. Haaland)

Nine botanical samples were taken in total (Table 6.1 and Figure 6.9 below). Five were block samples cut from selected quadrants during the process of excavation, as putative hearth contexts were identified. The remaining four were cut from the section profile using micromorphology sampling methods, that is, cutting small rectangular blocks of sediment from the section (Goldberg and Macphail, 2003). The blocks were cut using a leaf trowel, knife and chisels, but the samples were not kept oriented and could not be preserved as a solid block. The sediment in the

cave is very sandy and friable, even in dense deposits typical of occupational levels and hearths. The geoarchaeologists at Blombos encased the pre-cut block sample in plaster of Paris before finally removing the block from the section. In the case of all the block botanical samples, these were wrapped in self-adhesive plastic and then placed in a labelled bag. Fragments that fell on the floor were excluded from the sample to avoid contamination.

Table 6.1: Botanical samples' contexts, Blombos Cave (dates taken from Haaland *et al*., 2017)

Context	Context Type	OSL Date (ka)	Processing Method	Sampling Method
CFA F7b	Control	70±4	Micro-excavated	Cut from quadrants as putative hearths identified during excavation
CCC F7b	Hearth	74.6±3.9	Flotation experiment	
CFB-CFC	Hearth	68.8±4.6 - 75.5±5	Micro-excavated	
CFD G7a	Hearth	76.7±4.8	Flotation experiment	
CF h	Hearth	76.7±4.8 - 78.8±5.6	Micro-excavated	
CGAB h1	Hearth	81±4	Micro-excavated	Cut from section
CGAC G7b	Hearth	85±6	Micro-excavated	
CGAC H7a	Hearth	85±6	Micro-excavated	
CGAC I6c	Hearth	85±6	Micro-excavated	

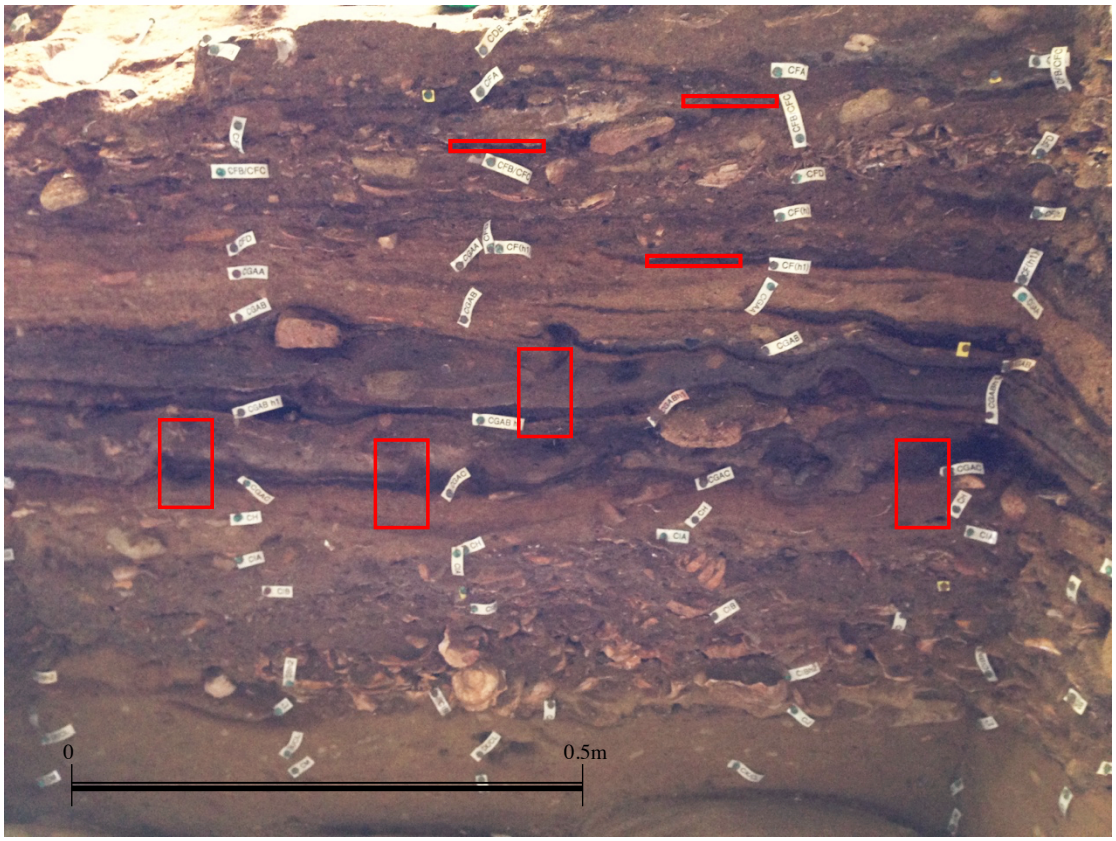


Figure 6.9: Botanical sample locations, south section Blombos Cave. Larger boxes indicate block samples taken from section, smaller boxes indicate samples taken during excavation (Image: C. Larbey)

6.4.2 Klasies River Main Site

The sampling strategy for the Klasies River Main site was refined based on the outcomes of those used at Blombos Cave. At Klasies River, the aim was to find undisturbed hearths from the oldest contexts possible but also from later periods to correlate results between different climate and cultural phases. The dating sequence at Klasies River is in the process of being updated. The most recent dates, using Uranium Thorium (U-Th), from the MSA1 levels of the Witness Baulk, Cave 1 have provided a date of 126 ± 1.5 kya in the SASU member level HHH (marked in Figure 6.11) (Wurz *et al.*, 2018). This level is 50-70cm above the levels from which the MSA 1 botanical samples were taken in the Light Brown Sand (LBS) member, the earliest of which (sample 4) was just above bedrock.

Caves 1 and 1B equate with the MSA 1 and MSA II phases, and the Witness Baulk is all that remains after Singer and Wymer completed their excavations of Cave 1 (Deacon and Geleijnse, 1988). The continued excavation of the southern

section of the Witness Baulk was the focus of the 2015 fieldwork season (blocked in red on the plan in Figure 6.10). There were significant beach deposits after 80 kya, attributed to high sea levels, but which also included various materials that had been transported down the slope, the effect of slump (Butzer, 1978; Deacon and Geleijnse, 1988). During the following MSA II or Howiesons Poort phase, only Caves 1A, possibly 1C and Cave 2 would have been accessible by early hunter-gatherers. It is from the Top Cutting of Cave 1A around the middle of the Howiesons Poort phase that the botanical samples were taken (marked in green on the plan in Figure 6.10.).

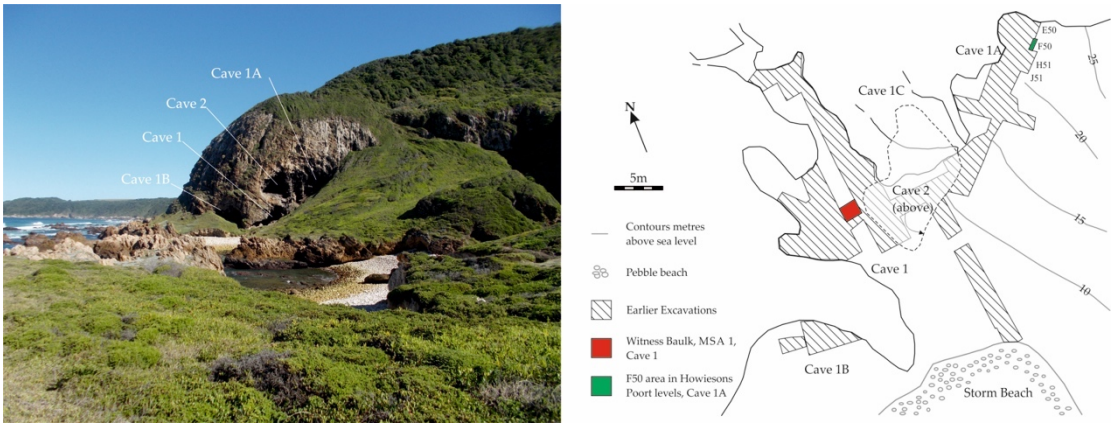


Figure 6.10: Klasies River main site and site plan showing sampling locations. (Images: C. Larbey)

Table 6.2: Botanical samples' context, Klasies River.

Context	Phase	Context Type	Date (ka)	Processing Method	Sampling Method
Cave 1A, Top Cutting, SE face, F50	Howiesons Poort	Hearth	~65	Micro-excavated	Block cut from section
Cave 1A, Top Cutting, SE face, F50	Howiesons Poort	Control - off hearth	~65	Micro-excavated	Block cut from section
Cave 1A, Top Cutting, SE face, F50	Howiesons Poort	Hearth (Right)	~65	Micro-excavated	Block cut from section
Cave 1, Witness Baulk, south section, SE face, on bedrock	MSA 1	Hearth	~130	Micro-excavated	Block cut from section
Cave 1, Witness Baulk, south section, SE face, 25 cm above bedrock	MSA 1	Hearth	~130	Micro-excavated	Block cut from section

During the fieldwork season, it was considered that only these few undisturbed hearths remained, despite substantial areas of apparent burning, hence only five samples were taken (Table 6.2).

The key difference between Klasies River and Blombos Cave was that these undisturbed hearths had been identified from previous micromorphological analysis and it was understood that the hearths were composed almost entirely of ash. The author decided, therefore, to take the block botanical samples from next to the scars left by the micromorphology sampling.

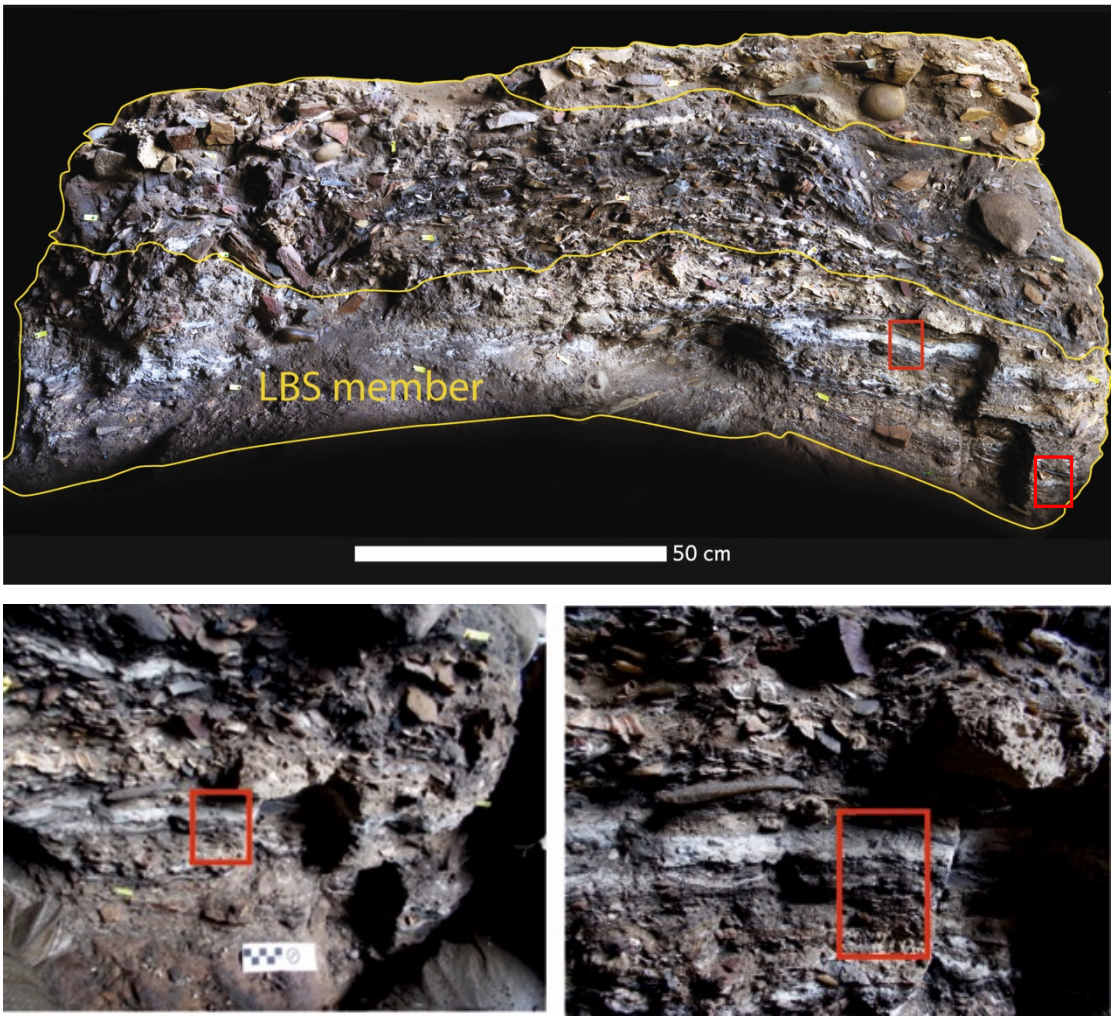


Figure 6.11: LBS member: Bottom left shows Sample 5 location and bottom right shows close up of Sample 5 location, from MSA 1 phase, SE face of south section, Witness Baulk, Cave 1, Klasies River (scale in 1xcm divisions). (Top image: S. Walker; bottom images: C. Larbey)

The samples from the southeast section of the lowest LBS member of the Witness Baulk (see Figure 6.10) (MSA I phase), equate with levels 38 and 39 of Singer and Wymer's excavations in the 1970s (Figure 6.11) (Deacon and Geleijnse, 1988).

Further undisturbed hearths were identified in the Howiesons Poort phase in Cave 1A, top cutting, see Figures 6.12 and 6.13. These equate to levels 15-17 excavated by Singer & Wymer (Singer and Wymer, 1982). The block samples in the Howiesons Poort phase were removed as described above, but at Klasies River, the samples were oriented, *i.e*. they were marked so that arrows indicated which was the top most level and which the lowest level. As with the samples at Blombos, however, the sediment was very friable and maintenance of the sample as a single

block proved difficult. The ash layers from the Howiesons Poort levels held together, however, very successfully in blocks.

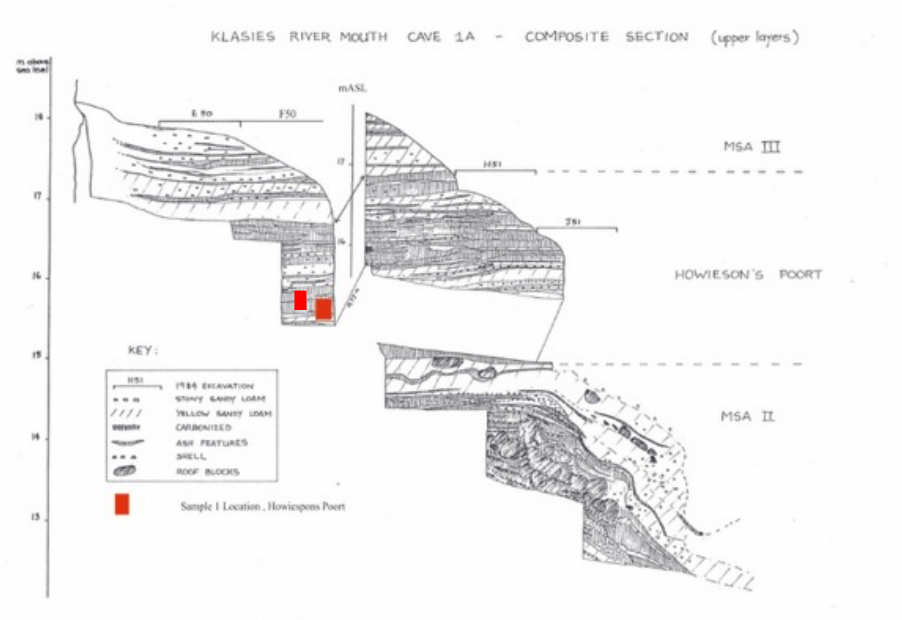


Figure 6.12: Elevation of Top Cutting, Cave 1A, Klasies River main site, sampling location. (Image: Singer & Wyman 1982)

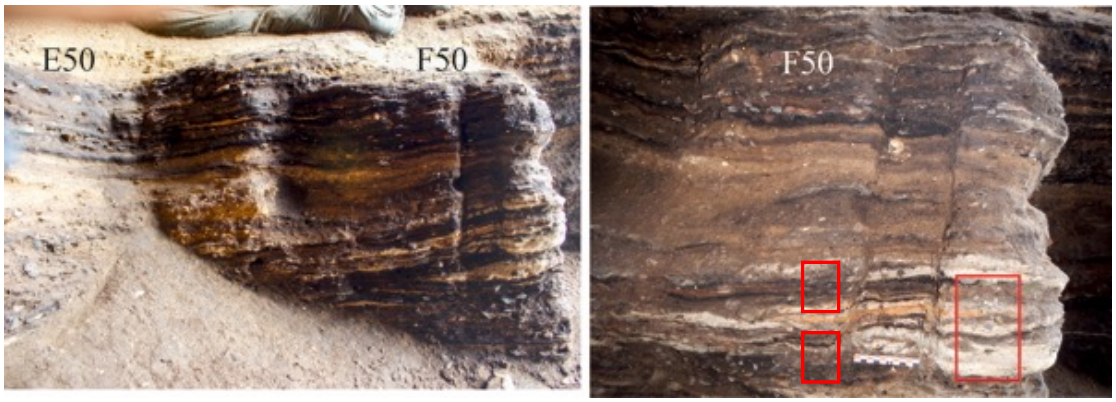


Figure 6.13: Red boxes indicate sampling locations at top cutting, Cave 1A, Klasies River main site. (Images: C. Larbey and S. Mentzer)

6.5 Laboratory Processing of Archaeological Samples

The following describes the processes used to prepare and analyse the samples in the George Pitt Rivers Laboratory, McDonald Institute for Archaeological Research, University of Cambridge (Table 6.3).

Table 6.3: Laboratory Process Summary

Samples weighed and volumes measured
(Easyweigh GT4800 digital scales)

⇓

Samples air-dried

⇓

Samples micro-excavated under a stereo-microscope
(Nikon SMZ800 x10, x20, x40).
Dental tools used to separate layers and featherweight spring forceps used
to sort samples and select artefacts and plant fragments

⇓

Fragments mounted onto Agar Scientific 25mm diameter, 8mm pin
SEM stubs, covered with 25 mm carbon adhesive discs, with fragment numbers
marked in white ink

⇓

Each stub was then analysed in a Hitachi TM 3000 environmental
scanning electron microscope. X30 and x40 magnifications were used
for whole fragment images and x300-x500 used for parenchyma and
morphological feature images.

⇓

Micrograph images taken and initial analysis recorded

⇓

Fragments stored on SEM stubs and curated in labelled
Agar Scientific SEM stub boxes (14 pin type)
Remaining samples analysed and processed as per normal post-ex.

⇓

Further analysis of micrographs and comparison of overall sample results
with micromorphology micrographs, organic petrology and FTIR analyses where
possible

Weights and Volumes

The volumes were taken in a volume-marked glass beaker and estimated only as the samples were fragile.

Air-Drying

The block sediment samples were air-dried; if placed in the Leec electric drier, the blocks of sediment hardened and became difficult to separate. The air-drying of the block samples made the charred fragments capable of being handled, although they were still very fragile. In an excavation context, charcoal from both Klasies River and Blombos had the consistency of butter, but if removed with surrounding sediment and left to dry out in a box, the charred fragments became viable, that is, capable of being handled in the normal way. This sampling technique was introduced to the sampling regimes at both sites, with a significant increase in charcoal collection as a result.

Micro-excavating and Sorting

Visible artefacts such as vertebrate remains, mollusc shells and lithics were removed via an initial screening process. Larger samples were sub-sampled to fifty percent by volume using a riffle box. During the sorting process, vertebrate remains (burned and unburned and macro and micro-mammal), lithics and mollusc shells were recovered. and these were recorded according to standard excavation procedures. These artefacts were counted, bagged and labelled (but not washed). All subsequent screening was performed under the stereo-microscope to identify putative charred plant remains. At the end of screening each sample, the putative plant fragments were mounted onto SEM stubs, labelled and placed into SEM storage boxes. Wood charcoal fragments were included in the assemblage for SEM analysis and proved a good comparison to distinguish parenchyma and root secondary xylem from wood.

SEM Analysis

The SEM analyses were made on full vacuum, in 'Analyses' mode. No gold sputter coating was used for these samples in order that samples were amenable to future analysis. A whole fragment micrograph was taken for each fragment and then subsequent images as appropriate.

Parenchyma Analysis

Initial parenchyma identification was made at the time of scanning and characteristics were recorded directly onto an excel spreadsheet. This process also meant that fragments analysed early in the research were re-visited after the benefit of greater knowledge and experience of the assemblage.

The aim of this process was to identify the presence/absence of cooked starchy plant tissue from hearths. Identification to species, genus or family was ideal but as it is difficult to identify species from fragments of parenchyma, the minimum requirement was, if possible, to identify charred parenchyma with its associated characteristics and other botanical remains such as seeds.

The process for sorting parenchyma used the selection process described in Chapter 3.

In addition to the modern reference collection created in this research and described below, much of the identification of parenchyma and general morphological features of starchy plant structures has come from the reference books created from the research by Jon Hather (Hather, 1988; Hather, 1991; Hather, 1993; Hather, 2000). Other publications from Lucy Kubiak Martens, Sarah Mason and Victor Paz have been particularly useful (Barker *et al*., 2007; Kubiak-Martens, 1996; Kubiak-Martens, 1999; Kubiak-Martens, 2002; Kubiak-Martens *et al*., 2015; Mason and Hather, 2000; Mason *et al*., 1994; Paz, 2005b).

Curation

The archaeological fragments are curated and stored on the SEM stubs in labelled stub boxes to minimize the amount of handling. Stub boxes are stored in the George Pitt Rivers Laboratory.

The import of samples and laboratory processes complied with the DEFRA Directive 2008/61/EC and the samples were imported into the UK under the appropriate licence for each year. The samples were also exported from South Africa under the appropriate licences from National Heritage Resources Act 25 1999.

6.6 Modern Reference Collection

The analysis of parenchyma and features of starchy plant tissue is limited by a lack of regional reference materials. Whilst text books are invaluable, there are invariably characteristics that might help in identifications and understanding regional variations. There are no such publications from South Africa as no such research studies have been conducted. It has been invaluable to be able to compare archaeological material with the reference collection. The collection created a better understanding of the biomes around the caves, particularly at Klasies River, and the variety of biomes meant that year-round plant food sources would have been available through varying climate conditions. In the laboratory, there was a tuber-bearing species *Aspargus sprengeri* that did not survive the drying process because the tubers were almost entirely comprised of water, and other species, such as *Watsonia* sp. corms that required longer burning because the corms have evolved to be resistant to wild fires. The comparison of SEM micrographs has supported the identification of features and in the case of two fragments to family. The following describes the method used to collect and create the modern parenchyma reference collection.

During each field season, first at Blombos then at Klasies River, modern plant samples were collected under licence. The plant collections were made in the

South African early Summer of November/December 2013 at Blombos and the summer period of February/March 2015 at Klasies River.

Underground storage organs have two purposes, firstly to provide energy for the plant growth in the spring/summer and secondly, for reproduction. If the key growth and flowering time for the plant is summer, then underground storage organs will be depleted, so prime harvesting times would be autumn and early spring.

Across the Cape Floristic Region (CFR) the availability of geophyte species is variable dependent upon the geophyte species; some species may have flowering times in the autumn and/or spring.

Table 6.4: Geophyte availability by season. (from de Vynck *et al*., 2016c)

Months	Season	Geophyte availability
July - December	Winter to early summer	High
January - April	Mid-summer to early Autumn	Lowest
May - June	Autumn	Variable

The February-March summer period is considered to be the 'carbohydrate-crunch' period (De Vynck *et al*., 2016c). De Vynck *et al*.'s research aimed to establish the foraging potential of carbohydrate resources in the CFR. This study established that hunter-gatherers would be able to forage sufficient carbohydrates to feed a family, year round across all vegetation types. During the Feb/Mar carbohydrate-crunch period, species available included *Watsonia* sp., *Pelargonium* sp., *Chasmanthe aethiopica* and *Rhoicissus digitata,* all of which feature in the plants collected for the modern parenchyma reference collection that were collected in February/March at Klasies River (see Table 6.4).

6.6.1 Blombos Cave Collection

Around Blombos Cave is a natural 'rock garden' of succulent and geophyte species. The surrounding landscape is a mosaic of primarily Strandveld, interspersed with Renosterveld, coastal littoral vegetation, and Albany thicket, the

latter characterised by milkwood, (*Sideroxylon inerme*). Proteas can be found in remnant Fynbos about five kilometres inland. Patches of rushes (*Typha* sp.) near the beach indicated the presence of fresh water seep (Figure 6.14).

Figure 6.14: Blombos Cave local vegetation: top left: succulent with taproot; top right: *Typha* sp. indicating fresh water seep; bottom left: milkwood thicket (*Sideroxylon inerme*), and bottom right: wild pincushion proteas (*Leucospermum cuneiforme*) in inland remnant Fynbos, close to Blombos Cave. (Images: C. Larbey)

As there was no available botanist on the project it was not possible to collect extensively and only common species and those recognisable as non-endangered were sampled under the project licence. The full list of species collected in Blombos is at Table 6.5. and the species list collected in Klasies River is in Table 6.6.

The full modern parenchyma reference collection with SEM micrographs can be found in Appendix Ia and Ib and the spreadsheet collecting and analysis raw data can be found in Appendix Ic.

Table 6.5: Modern root and tuber samples collected from around Blombos Cave.

Classification	Sample No.	Name	Family	Common Name
Dicots	BBC-10	*Elytopappus rhinocerotis*	Asteraceae	
	BBC-11	*Felicia* sp.	Asteraceae	
	BBC-01	*Felicia amoena latifolia*	Asteraceae	Felicia
	BBC-06	*Pelargonium* sp.	Geraniaceae	
	BBC-08	*Pharnaceum dichotum*	Aizoaceae	Radish
	BBC-05	*Rhoicissus tridentata*	Vitaceae	Wild grape
	BBC-02	*Ruschia geminiflora*	Aizoaceae	
Monocots	BBC-09	*Bowiea vollibilis*	Hyacinthaceae	Climbing Potato
	BBC-07	*Lachanalia*	Hyacinthaceae	
	BBC-12	*Ledebouria revoluta*	Liliaceae	
	BBC-04	*Massonia pustulata*	Asparagaceae	
	BBC-03	*Watsonia* sp.	Iridaceae	

All species were collected from the immediate vicinity of Blombos Cave, with the exception of the *Ledebouria revolute* that came from the Fynbos behind the Blombos site. The particularly heavy rains during the rainy season that had washed out part of the road and some of the paths around Blombos had also washed out plants, corms and tubers from the rocky slopes around the cave, making collection easy and identification more complex.

6.6.2 Klasies River Collection

Plant collection and identification at Klasies River were significantly aided by the project botanist, Dr. Yvette van Wijk (Compound Voucher YvWijk 6382). The identifications were made by Dr. van Wijk both in the field and confirmed in the field laboratory before processing. The micro-biomes around Klasies River were

mapped by Dr. Yvette van Wijk (Figure 6.15) and reference samples collected for this research were recorded within the same area numbers (van Wijk *et al*., 2017).

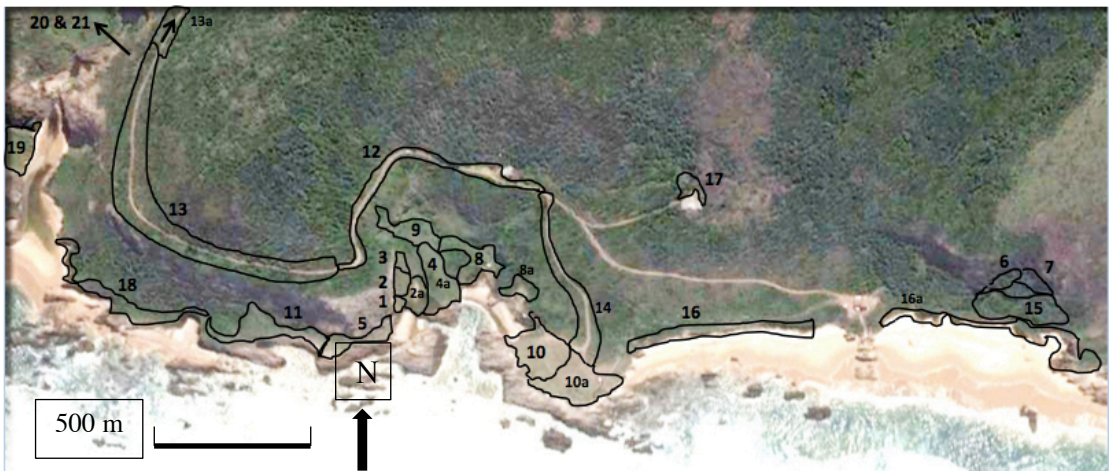


Figure 6.15: Klasies River plant collecting map, each number representing a different vegetation area. (map from van Wijk *et al*. (2017))

1	Entrance to Cave 1A – worn and trampled succulents and grass
2	Eastern edge of Cave 1C – disturbed and unstable
2a	Low vegetation, east of Area 2 – fresh water seep present
3	Milkwood forest and thicket from 20cm-2m high beside Cave 1C
4	Concave slope rising north, grass species rich, wind-sheared vegetation
4a	Similar to 4 but including wind-sheared 'Lilliputian' forest and thicket species
5	Steep slope between shore and cliff to Cave 1B – low grassy wind-sheared thicket species
6	Entrance to Cave 3 – dense thorny thicket and forest
7	Entrance to Cave 4 – thorny thicket, succulents and herbs
8	Mixed species, grass-rich vegetation, thicket in lee of wind
8a	Dense vegetation, mostly thicket and forest up to 2.5m high
9	Long valley sloping steeply up west, grassy, succulents, geophytes, thicket in lee of wind
10	Grassy flats between cliffs and seashore, low grass, succulents, coastal/littoral
10a	Similar to 10 but with low shrubby and succulent littoral species
11	From edge of rocks above seashore, low grassy scrub to thicket 1m high
12	Both sides of entrance road, sloping south, dense coastal thicket
13	Both sides of entrance track sloping west, thicket, forest, lianas
14	Both sides of entrance track sloping north, thicket and few Fynbos species
15	Small coastal forest patch below Caves 3 and 4, sheltered by fore-dune with thicket
16	Narrow band on edge of beach and fore-dune, low costal vegetation, thicket at eastern end
17	Small patch of 3-4 m high forest and thicket, some disturbed grassy areas
18	Along footpath above rocky edge to seashore, thicket to 1.5m+, below forest patch
19	Small beach and cliff on west bank of Klasies River, ravine and estuarine vegetation
20	Inland Fynbos remnant (next to inland pond where indigenous water lilies were found)
21	Inland Forest remnant

Figure 6.15 indicates areas from which plants were collected. These areas were defined by different geography, although some species cover several areas. Coast margins, Albany thicket and Afro-Montane Forest tend to have specific species.

The forest yielded only a rhizome of *Aristea ecklonii*, belonging to the Hyacinthaceae family. All the species of ferns in the forest would also have had rhizomes but these species are protected, and therefore could not be sampled.

However, a common fern species, *Asplenium* sp., was sampled from the Klasies River ravine area.

The coast foredune was one of the most productive areas, where ten minutes' collecting whilst sitting in one place produced a species of *Silene* taproot, wild carrot (*Daisispernum suffruticosm*) and tubers of cobra lily (*Chasmanthe aethiopica*) sufficient to feed a family of six people (Figure 6.16A). Most coastal foredunes are rich in starchy food plants, regardless of climate (apart from ice) (Graham-Brown, 2007b). Albany thicket and forest included species such as milkwood (*Sideroxylon inerme*) and existed in patches with kloofs (ravines) and on hills. This biome was not rich in geophytes but even here *Trachyandra ciliata* or veldkool was recovered (Figure 6.16B). Two kilometres inland is remnant Fynbos with proteas. It is described as remnant because it is surrounded by cultivated farmland or dairy pasture. This area also included a pond in which grew and thrived South Africa's only indigenous species of blue water lily (*Nymphaea nauchali*) and an unidentified species of reed (Figure 6.16C).
The river valley and estuary area of Klasies River is much diminished by the heavy use of water upstream by a 1300-strong herd dairy farm. However, the river ravine produced species such as arum lily bulbs (*Zantesceschia aethiopica*) (Figure 6.16D), hens & chickens tubers (*Chlorophytum comosum*), spleenwort (*Asplenium* sp.), white powder puff bulb (*Haemanthus albifloss*), asparagus tubers (*Asparagus sprengeri*) and a reed rhizome (*Juncus puuctorius*). The species from the ravine reveal that sedge grasses would have been only one food resource from Klasies River riparian vegetation.

A  B 

C  D 

Figure 6.16: Plant collecting in different vegetation types around Klasies River. A: foredune coastal vegetation below caves 3 and 4 at Klasies River (area 16); B: dense thicket and forest in foreground of image by Klasies River main site (area 8a); C: author in remnant Fynbos by inland pond (area 20); D: author in Klasies River ravine (area 19). Numbers in brackets relate to plant collecting map Figure 6.15. (Images A & B: C Larbey; Images C & D: Yvette van Wijk)

Table 6.6 indicates the full list of species collected from the various biomes around the Klasies main site.

Table 6.6: Modern root and tuber samples collected from around the Klasies River Caves (* denotes in Asparagales order)

Classification	Sample No.	Name	Family	Common Name
Dicots	KR15-35	*Commelina africana*	Commelinaceae	
	KR15-24	*Daisispernum suffruticosm*	Apiaceae	Wild Carrot
	KR15-36	*Dipogon lignosus*	Fabaceae	Cape Sweet Pea
	KR15-07	*Haplocarpha nervosa*	Asteraceae	
	KR15-02	*Kedrostris nana*	Cucurbitaceae	Stinky Potato
	KR15-15	*Lichtensteinia sp.*	Apiaceae	
	KR15-17	*Nymphaea nauchali*	Nymphaceae	Blue Water Lily
	KR15-03	*Plantago crassifolia*	Plantaginaceae	Plantain
	KR15-13	*Rhoicissus digitata*	Vitaceae	Wild Grape
	KR15-05	*Silene primuliflora*	Carophillaceae	
	KR15-06	*Silene undulata*	Carophillaceae	
	KR15-22	*Silene* sp.	Carophyllaceae	
	KR15-31	*Tephrosia capensis*	Fabaceae	
	KR15-39	*Vigna unguiculata*	Fabaceae	Wild Cow Pea
Pteridophyta	KR15-27	*Asplenium* sp.	Aspleniaceae	Spleenwort
Monocots	KR15-37	*Albuca virens*	Hyacinthaceae*	
	KR15-38	*Aristea ecklonii*	Iridaceae*	
	KR15-29	*Asparagus sprengeri*	Asparagaceae*	
	KR15-12	*Bonata speciosa*	Orchidaceae*	Wood Orchid
	KR15-21	*Chasmanthe aethiopica*	Iridaceae*	Cobra Lily
	KR15-26	*Chlorophytum comosum*	Asparagaceae*	Hens & Chickens
	KR15-08	*Cyperus rotunda*	Cyperaceae	Nut Grass
	KR15-10	*Drimia unifloria*	Hyacinthaceae*	
	KR15-28	*Haemanthus albifloss*	Amarilladaceae*	
	KR15-32	*Hypoxis* sp.	Hypoxidaceae*	
	KR15-16	*Juncus puuctorius*	Juncaceae	Reed
	KR15-11	*Ornithogalum* sp.	Hyacinthaceae*	
	KR15-34	*Ornithogalum graminifolium*	Hyacinthaceae*	
	KR15-04	*Oxalis* sp.	Oxalidaceae	
	KR15-19	*Prionium serratum*	Thurniaceae	Palmiet
	KR15-23	*Prionium serratum*	Thurniaceae	Palmiet
	KR15-09	*Satyrium* sp.	Orchidaceae*	Orchid
	KR15-01	*Trachyandra siliata?*	Asphodelaceae*	
	KR15-20	*Triglochin* c.f. *elongata*	Thurniaceae	
	KR15-18	*Watsonia* c.f. *pillansia*	Iridaceae*	
	KR15-25	*Zantesceschia aethiopica*	Araceae	Arum Lily

Significant is the number of monocots represented and those belonging to the order Asparagales (Table 6.6). The Blombos list, by contrast, contains few

monocots (Table 6.5). This is significant for two reasons; firstly that the storage organs of monocots have been found in many other pre-agricultural, hunter-gatherer archaeological sites across the world and, in particular, with similar species to species recovered from LSA contexts in South Africa (Table 6.6); and secondly because both Deacon and Jones have suggested that the distinct parallel-veined leaf of monocots signals to foragers that there is a starchy tuber, rhizome, corm or bulb beneath the ground (Deacon, 1976; Jones, 2009b). This monocot leaf acting as a 'flag' would allow people to forage for food in new environments (Jones, 2009b).

Cyperus usitatus also appears in the South African archaeological record (Table 6.6), but has been noted in archaeological assemblages all over the world (Chapter 4). Semi-aquatic sedges and reeds appear in all the archaeological assemblages in the LSA contexts. *Cyperus* has been sampled, together with *Oxalis* sp. and *Hypoxis* sp., also listed. *Moraea* sp. appears in two assemblages (Table 6.7); many species of this taxa are toxic so may not be in the assemblage as food (Youngblood, 2004).

Table 6.7: Plant species from Eastern and Southern Cape LSA archaeological sites. Adapted from Deacon (1972))

Site	Hoffman's Cave	Scott's Cave	Spring's Shelter	Melkhoutboom Cave	Highlands Rock Shelter	Tafelberg Hall Shelter
Habitat	Coast (Robberg) 15 m asl	Coastal Valley, 67 m asl, 20 km inland	Cape Folded Belt, 610 m asl, 50 km inland	Cape Folded Belt, 762 m asl, 50km inland	Interior plateau, 1326 m asl, 230km inland,	Interior plateau, 1372 m asl, 280km inland
Phase	LSA	LSA	LSA	LSA	LSA	LSA
Bedding	*Zostera capensis*	*Danthonia* sp. & other grasses	Grasses	*Themeda triandra, Koeleria cristata*	Grasses	None recorded
Raw materials	None recorded	*Cyperus textilis*	*Cyperus textilis, Phragmites communis*	*Cyperus textilis, Phragmites communis*	*Cyperus textilis, Phragmites communis*	None recorded
Main edible plants	None recorded	*Watsonia* sp. *Freesia* sp. *Cyperus usitatus* *Schotia afra* *Amarantus* sp. *Harpephyllum caffrum*	*Watsonia* sp. *Freesia* sp. *Moraea* sp. *Schotia afra* *Oxalis* sp.	*Hypoxis* sp. *Watsonia* sp. *Freesia* sp. *Moraea* sp. *Bulbine alooides* *Oxalis* sp. *Cyperus usitatus* *Schotia afra* *Harpephyllum caffrum*	*Cyperus ustitatus* *Bulbine alooides* *Freesia* sp.	*Cyperus ustitatus* *Bulbine alooides*

Watsonia pillansia corms were sampled from Klasies River and Blombos Cave. The sheaths and corms of *Watsonia* have been found at Strathalan B Cave, Scotts Cave, Springs Rock Shelter, de Hangen and Melkhoutboom Caves, South Africa (Deacon, 1972; Deacon, 1976; Deacon, 1993; Opperman, 1996; Parkington and Poggenpoel, 1971). There are also records of historical use by the San Bushmen (Schapera, 1930; Steyn, 1984; Steyn, 1990) and modern research that asserts their availability year-round and that *Watsonia* remains are commonly associated with archaeological sites (De Vynck *et al.*, 2016c; van Wijk *et al.*, 2017).

This taxon has evolved to be fire resistant and although it does not need fire in order to reproduce, it flowers profusely after wild fire (Manning, 2008). Savanna chimpanzees (*Pan troglodytes*) from Fongoli, Senegal are known to exploit vegetation such as starchy *Watsonia* corms and bamboo stems after wild fires (Figure 6.17) (Pruetz and Herzog, 2017), it seems possible that early humans may have learned to adapt to cooked foods and even to cook certain species in this way.

Figure 6.17: Chimpanzees from Fongoli, Senegal navigating a burned landscape. (Image: Pruetz & Herzog, 2017: S345)

Many of the same species were present at both Blombos and Klasies River although the mosaic of vegetation types around each cave was quite different.

6.6.3 Modern Reference Collection Creation - post-collection processes

The plant specimens were photographed and then dried before transport. Each dried specimen was placed in an acid-free paper bag and labelled but transported in triple plastic bags and a container. In the laboratory, the specimens were further dried in the electric Leec drier. Where possible, dried specimens were labelled and curated and are currently kept in the George Pitt Rivers Laboratory as a dried parenchyma reference collection for the Cape coast of South Africa.

Each plant species was burned and the burning process followed the protocols suggested by Hather (Hather, 1993). Most of the specimens were wrapped in aluminium foil to exclude oxygen and burned for 2.5-3 hours in a muffle furnace at 300°C. Some of the larger, more dense fragments and those species that were naturally fire resistant, such as *Watsonia*, were burned for a further 30 minutes.

The exceptions were small bulbs, which were burned for 2.5 hours in the muffle furnace at 250°C.

The burned samples were then fractured using a razor blade, or broken along a plane, especially Transverse Section (TS) (across) and Transverse Longitudinal Section (TLS) (lengthways), where possible. These fragments were then mounted on SEM stubs, with gold cover, which is used to stop charging in the SEM and gives a finer resolution to the micrograph. However, this also prevents any further assessment of the samples. The samples were analysed using an environmental scanning electron microscope that provides sufficient diagnostic detail without destroying the artefact. The fragments are curated permanently mounted on the SEM stubs in labelled SEM stub storage boxes for future analysis.

Whilst the modern parenchyma reference collection is small and represents a small percentage of the potential species that may be available in the vicinity of the caves, the specimens represent a first step in such a collection and appear to be representative both of the seasonal availability and of those species already recovered from archaeological assemblages in South Africa.

6.7 Suggestions about Methods

The preservation conditions from Blombos and Klasies River have meant that solutes and the peri-mineralisation process have prevented the author from using a flotation system for collecting charred plant samples. Block sediment sampling, together with co-operation with micromorphology, micro-FTIR and organic petrology analyses, although time-consuming, have been ultimately productive in providing answers to research questions about cooked plant foods from difficult, but important sites. It may be that in other caves and in open sites, flotation is possible, which would save time but it is recommended to take block, untrowelled samples from the middle and edges of the hearth, if possible alongside micromorphology samples in order to understand fully the micro-context.

Hearths are, and have been, the centre of social life and yet the spatial and temporal relationship between hearths is often unknown. In Palaeolithic

excavation, quadrants may cut through hearths and each part may be excavated by different people at different times (Figure 6.18). Total-station piece-plots of top, bottom and sides of hearths would allow provide the ability to assign hearths to dated contexts and enhance spatial resolution.

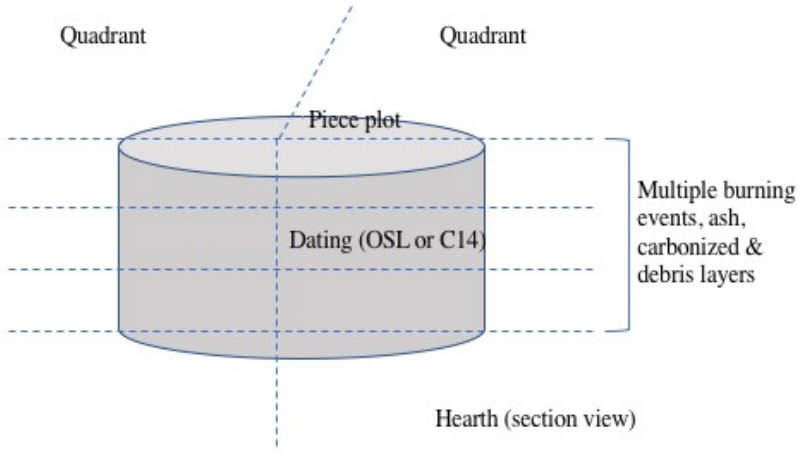


Figure 6.18: Hearth excavation and sampling diagram. (Image created by C. Larbey)

There are questions that would be useful to address at Klasies River, where many of these hearths have been noted: how many of the hearths were contemporary; and how far apart were the contemporary hearths? These data would help to answer social questions such as how big might the band have been and even whether these hearths might have belonged to nuclear families.

6.8 Conclusion

There was a considerable learning process that occurred through the scanning of these assemblages both at screening and SEM analysis stage. There was, therefore, corresponding re-analyses of the assemblages. When it comes to analysing these assemblages in the wider context of the macro-context, *i.e.* the layer from which it came and the surrounding archaeological evidence, analysis becomes more complex.

Archaeobotanical analysis conducted as part of an ongoing excavation is able to understand the macro-context, level by level. The majority of these samples came from the sections exposed by previous excavations and, where some of those excavations were 30-40 years ago, it was difficult to track the quadrant and layer

numbers. In general, this information is available in publications and it provides the background data for faunal, mollusc and lithic remains but not specifically about hearths. Hearths are described and discussed in the excavation texts but not recorded as features so there is a lack of continuity (Deacon, 1995; Deacon and Geleijnse, 1988; Singer and Wymer, 1982). The data provided by the micro-context information proved invaluable in: a) confirming that the context was an intact hearth feature; b) providing evidence of multiple burning events; c) giving detailed analysis of other foods cooked in the hearths; and d) demonstrating the temperature ranges across the hearth and defining the stratigraphic relationship between the debris layer and the hearth contents. This micro-context profile allowed the identification of non-hearth areas such as occupation layers.

This innovative extension of method described above was the result of the multi-disciplinary team ethos in both projects. In both projects the author had the opportunity to excavate, as well as taking samples, providing significant insights into evidence of other activities and diets of the humans that occupied these sites; insights that will help interpret findings.

Chapter 7

Results and Analysis – Klasies River and Blombos Cave

7.1 Introduction

This chapter sets out the results and analysis of the botanical samples from the hearths of Klasies River and Blombos Cave. The Klasies River samples came from the earliest MSA I phase (MIS 5e, c. 120 kya) just above bedrock in Cave 1 and the Howiesons Poort phase (MIS 4, c. 65 kya) in the middle of the sequence in Cave 1A. The Blombos samples came from the MSA II phase OSL dated 85±6 to 81±4 kya and from the Still Bay phase OSL dated 69.7±3.9 to 78.8±5.6 kya.

The results of the botanical analysis of each sample are presented as tabulated results followed by SEM micrographs enabling the presentation and analysis of the plant remains. The categories of features from each sample will be illustrated, together with detailed explanations of how the fragments were assigned to a category. The identification of parenchyma, starchy plant characteristics and signs of processing are the primary focus. Not every fragment of parenchyma is presented in these chapters but the examples used are to illustrate the nature of the sample. The quantification of these results are tabulated, using density analysis results and visualised as a chart.

The categories used for assigning fragments were identified in Chapter 3 and include:

> (a) parenchyma, which includes any identifiable parenchymous tissue, although sources, *i.e.* from tuber or rhizome are identified and justified where possible;
> (b) fused parenchyma, where the cell structure has become deformed and thickened by carbonisation to the point where it appears solid or has a vitreous, glass-like appearance;

(c) crystals, raphide and rhomboid crystals which are common in roots and tubers and druse crystals are slightly more rare. These are recorded.
(d) secondary root xylem, which is indicative of starchy roots and is included as a category;
(e) seeds, fruits, nuts or legumes, which are only included if found;
(f) Wood charcoal;
(g) unidentified plant tissue – this category contains mostly vascular tissue that can be seen but if there is just non-vascular matrix visible then it is just classified as unidentified (unid). Included in this are borderline cases that are discussed and illustrated;
(h) mixed matter – this is where the author considers this may be faecal matter or some comminuted material;
(i) bone – occasionally blackened bone fragments were amongst the assemblage as it was easy at the initial screening stage to mistake the blackened spongy layer for parenchymous tissue;
(j) sediment - the positive ions within the ash behaved like clay platelets and burned sediment/ash and plant remains occasionally clustered together into small fragments. This phenomenon has previously been observed by Weiner (Weiner, 2010);
(k) disrupted parenchyma, which was a category of parenchyma that only applied to two contexts in Blombos Cave, with interesting results but at the time was categorised this way because it was different. Here the cell structure was not always fractured and, therefore, occurred before burning. The cell walls were deformed, sometimes with a folded appearance and tended to have collapsed inwards;
(l) broken parenchyma, which was isolated to provide a contrast with the disrupted parenchyma category, where the fragments had been fractured by mechanical force (trampled) and had angular and straight edges. These were only found at Blombos.

All the SEM micrographs taken for this research have been placed on an USB stick and a copy has been placed in the GPR laboratory with the parenchyma modern reference collection and a copy sent to Witwatersrand University so that they are made available for other researchers. The data will also ultimately be

made available online through Researchfish. The archaeological assemblage is curated on SEM stubs and placed in boxes in the GPR laboratory and is available for other research, especially as gold sputter was not used in the SEM process.

This research benefits extensively from the additional contextual understanding available from other archaeological science disciplines. To understand the micro-context of the results, this chapter will start with the findings of the analyses from the micromorphology, FTIR and organic petrology samples, where available.

7.2 Klasies River

7.2.1 Cave 1, MSA I Phase - Geoarchaeological Results

The micromorphology sample in Figure 7.1 relates to botanical sample 5 and shows the carved block about to be removed from the section, and the subsequent thin section images showing features from that block. The analysis indicates that the hearth was built on debris layers, that were rich in marine shell. The debris layers also contained vertebrate remains that were either unburned or had been exposed to a moderate amount of heat and were concentrated under the lower ash unit (lower arrow Figure 7.1) but few vertebrate remains were included in the Cave 1 hearths (Mentzer, 2016, Pers. Comm.).

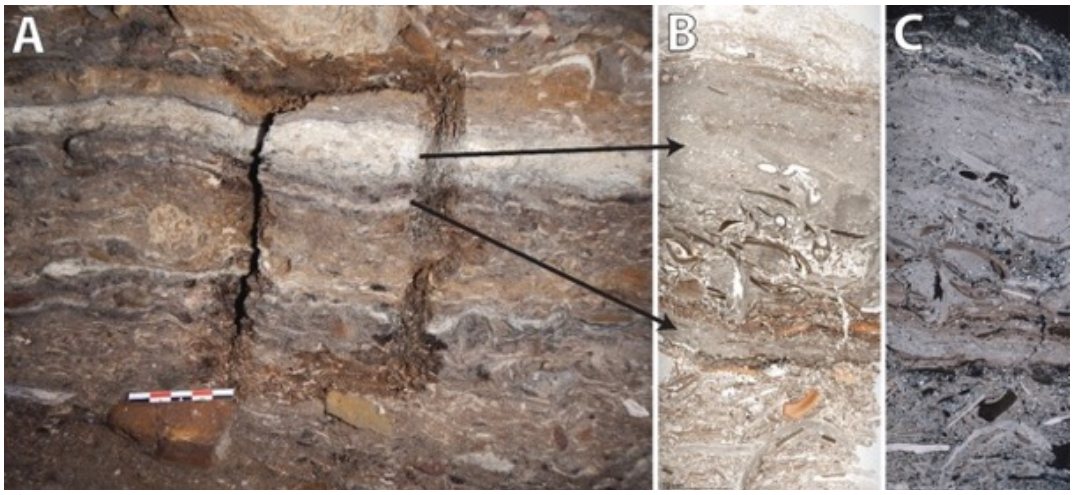


Figure 7.1: Location of micromorphological sample in Klasies River Cave 1, MSA I phase. A) The carved block in the south-facing profile contains a thin layer of ashes overlain by a thicker layer of ashes and shell (see Figure 6.10 for sample location). B) Composite image of the two ash layers in thin section with arrows indicating relationships to the features in the field. Seven discrete units are visible here. From the base to the top: debris rich in bone and shell, ash, charred material and bone, ash mixed with shell, pure ash, debris rich in shell, sterile sand in plane polarised light (PPL). C) Same view as (B) in cross polarised light (XPL). Scale in cms. (Image: S. Mentzer from Larbey *et al*., 2019)

The ash layers proved to be to intact hearths, where the fuel had burned to completion in oxidising conditions, with no charred substrate. Layers of re-crystallised ash-derived carbonate and thin lenses of sand in the ash layer may be the result of multiple burnings.(Mentzer, 2016, Pers. Comm.). The internal stratigraphy suggestive of multiple hearth use haw been observed in other Pleistocene contexts (Berna and Goldberg, 2007; Mallol *et al*., 2013a)..

The organic petrology analysis indicates that the organic elements in the debris layer underwent peri-mineralisation (the process of being mineralised), a process that could take months (or seasons). This would suggest that the debris layer was not associated with the burning events. This analysis also confirmed the presence of fat-derived char associated with burned bone and charred plant remains present in the ash layers (Mentzer, 2016, Pers. Comm.).

7.2.2 Cave 1A, Howiesons Poort Phase – Geoarchaeologal Results

As with Cave 1, the deep ash layer from the sample in Cave 1A corresponds to two burning events (Figure 7.2). It is not known from which of these events the plant remains were recovered as it was not possible to differentiate visually at the time of sampling or of initial sorting. The zones of re-crystallised carbonates (from wood ash) and partially phosphatised ashes created by surface exposure, suggest further burning events over short intervals (days). These ash layers are also set upon debris layers, similar in composition to those of Cave 1, although the ash layer has a larger content of burned bone, but less marine shell. The lower ash layer is capped with a thin layer of debris that is rich in organic material and bone (Mentzer, 2016, Pers. Comm.).

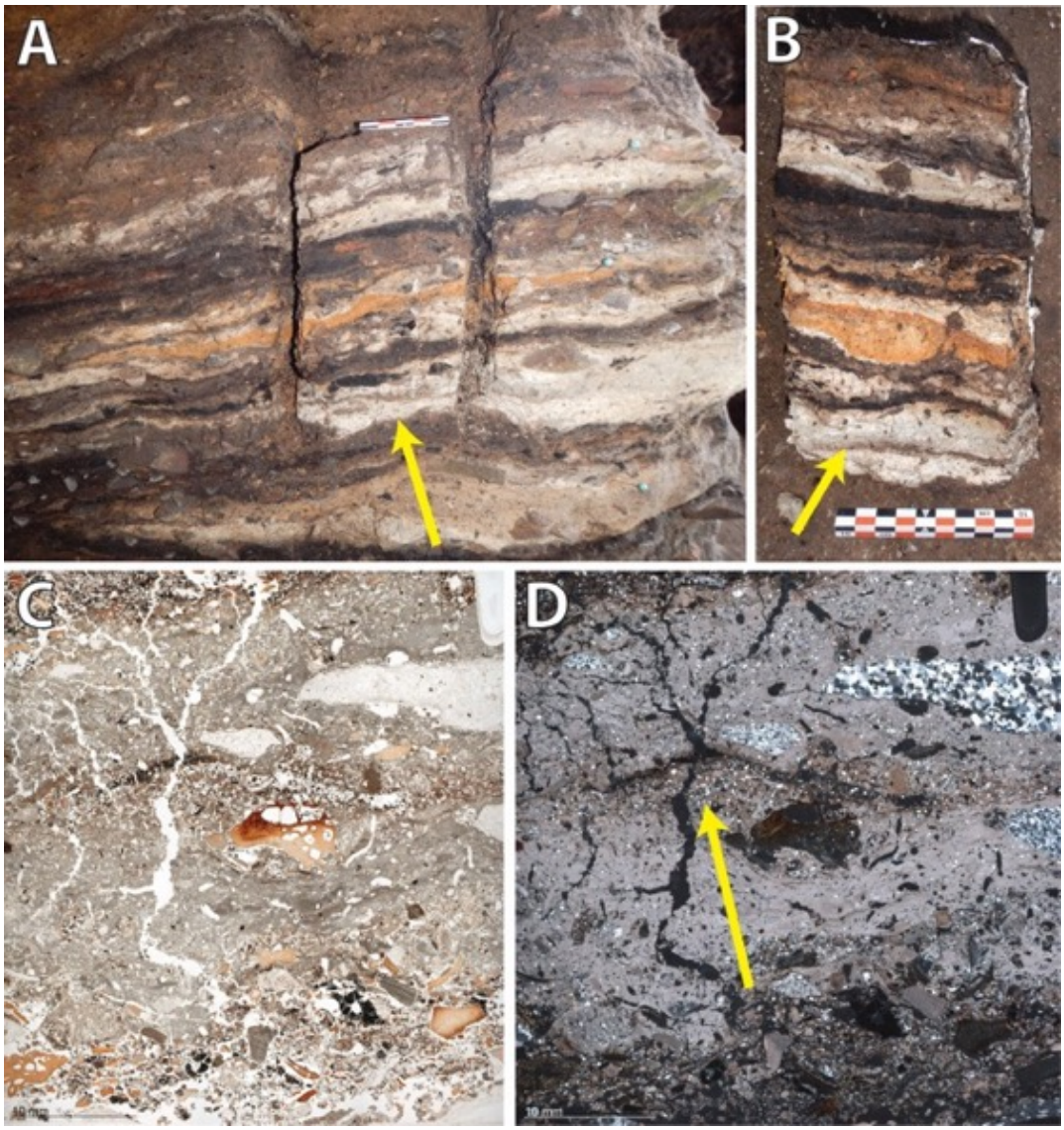


Figure 7.2: Location of the micromorphological sample in Klasies River Cave 1A, Howiesons Poort phase. A) The carved block in the north-facing, southern profile contains a thick layer of ashes at its base (arrow). B) The block removed, with thin dark layer (arrow) visible that divides the ash layer into two units. C) Composite image of the two ash layers in thin section, PPL. D) Same view as (C), XPL. The two ash layers are separated by a thin layer of debris that is visible here as an increased concentration of quartz sand (arrow). Scale in cms. (Image: S. Mentzer from Larbey *et al*., 2019)

The FTIR measurements, used to assess heating temperatures of the hearth, strongly suggest that the temperatures within the ash layer exceeded 550°C, but possibly for only a short period of time (Berna and Goldberg, 2007; Berna *et al*., 2012; Guo and Bustin, 1998). The implication is that these fires were short and functional.

The organic petrology analysis indicates a wider variety of plant tissue than seen in Cave 1, including stems, leaves, fibrous tissues and woody tissues. Again fat-

derived char associated with bone indicates that the some bone fragments were heated while fresh (Ligouis, 2017).

Parenchyma was identified in the thin section micrographs from both hearths in both phases (Figure 7.3). Three fragments come from Cave 1A in the Howiesons Poort phase, with the fragments in Figure 7.3C and 7.3E probably coming from monocot stems.

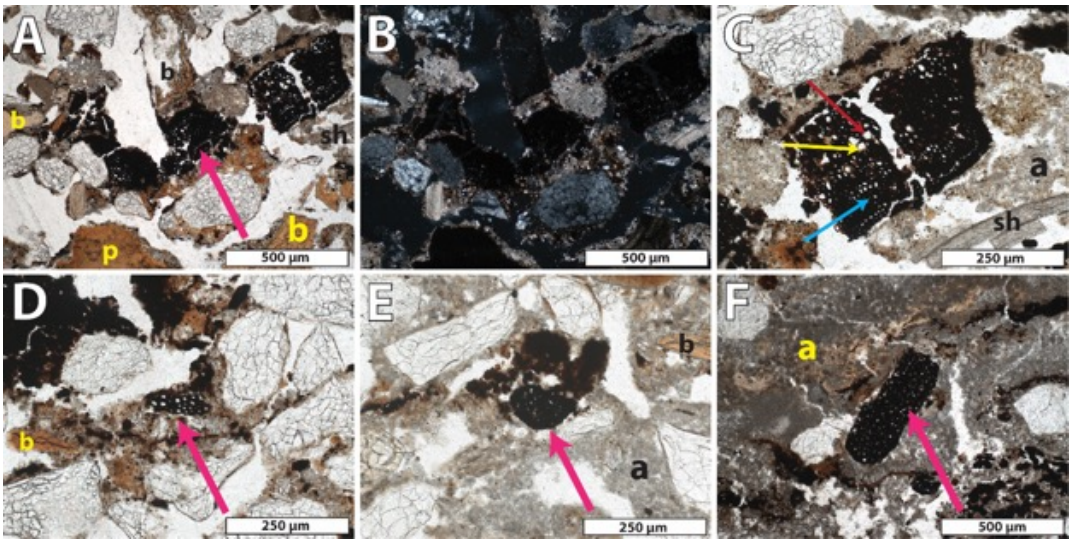


Figure 7.3: Parenchyma visible in thin section. A) A fragment of rhizome parenchyma from Klasies River, Howiesons Poort phase, Cave 1A (arrow), PPL. Fragments of bone (b) and a phosphatic grain that may be guano (p) are also visible. B) Same view as (A), XPL. C) Detail of the fragment with identifiable structures related to a vascular bundle in the stele of the rhizome, PPL. Blue arrow: parenchyma. Yellow arrow: xylem. Red arrow: phloem. Also visible: shell (sh) and ash (a). D) Another fragment from Cave 1A (arrow), PPL. E) A third fragment from Cave 1A (arrow), PPL. F) A fragment from MSA I phase Cave 1 (arrow). (Image: S. Mentzer from Larbey *et al.,* 2019 and parenchyma identifications: C. Larbey)

In subsequent extensive micromorphology analysis of the Klasies River site, more than 55 undisturbed but single-use hearths were identified. It was only possible to identify these hearths under the microscope in thin section and they would not have been visible in section (Mentzer, 2016, Pers. Comm.). This finding, however, makes the four hearths sampled exceptional in their multiple use.

7.2.3 Klasies River Botanical Results

The block botanical samples from Klasies River were cut from section profiles that had been exposed by previous excavations (Table 7.1). The MSA I phase of the southern section of the Witness Baulk in Cave 1 had been exposed by Singer and

Wymer in the 1970s/80s and the east face of the Top Cutting of Cave 1A in the Howiesons Poort phase had been exposed in the 1980s/90s by Hilary Deacon (Deacon and Geleijnse, 1988; Singer and Wymer, 1982). None of the samples was taken from the ongoing excavation. Samples 1, 2, 4 and 5 were all classified as Class A samples (Hubbard and Clapham, 1992). Sample 3 was a more ambiguous sample coming from a level associated with a hearth but not in the hearth. These samples are also important as any parenchyma within these samples demonstrate a background signature of parenchyma.

Table 7.1: Summary of botanical samples data from Klasies River Main Site, South Africa.

Sample No.	Location	Phase	Unit Reference	Volume (ml)	Weight (g)	Date (kya)	Comments
1	Cave 1A, Top Cutting East Face	Howiesons Poort (MIS 4)	F50* Levels 15-17	300	239	65	Ashy hearth. Base rhs of micromorph
2	Cave 1A, Top Cutting East Face	Howiesons Poort (MIS 4)	F50 Levels 15-17	150	137	65	Ashy hearth. Base lhs of micromorph
3	Cave 1A, Top Cutting East Face	Howiesons Poort (MIS 4)	F50 Levels 15-17	150	139	65	Debris layer near hearth SE of micromorph scar
4	Cave 1, Witness Baulk, South Face, LBS member	MSA1 (MIS 5e)	Levels** 38/39	140	127	120	Ashy hearth - 25 cm above bedrock
5	Cave 1, Witness Baulk, South Face, LBS member	MSA1 (MIS 5e)	Levels 38/39	200	190	120	Ashy hearth - Just above bedrock

* Samples taken from the middle of the Howiesons Poort phase relate broadly to the quadrant and layers from the Singer & Wymer excavation F50, levels 38 and 39 (Singer and Wymer, 1982); ** the samples from the LBS in the Witness Baulk correspond to the Singer & Wymer excavations level numbers 38 and 29 (Deacon and Geleijnse, 1988). lhs = left hand side and rhs = right hand side of the scar left in the section profile after the removal of the micromorphology sample.

Howiesons Poort Phase, Cave 1A

Sample 1

From: F50 15-17, East Face, Top Cutting, Cave 1A (Howiesons Poort Phase)

Botanical Remains from Sample 1

Table 7.2: Botanical results from Sample 1, F50, Levels 15-17, East Face, Top Cutting, Cave 1A, Klasies River

No. Fragments	Category
Ash Layer	
5	Parenchyma
2	Monocot stems
1	Fused starch
1	Druse crystal
2	Secondary root xylem
5	Wood charcoal
10	Unid plant tissue
26	Total from Ash Layer
Carbon-rich substrate	
8	Wood charcoal
5	Secondary root xylem
18	Unid plant tissue
2	Mixed plant matter
33	Total from Substrate

The categories for the identification of plant remains recovered have been discussed in Chapter 3.

The rhizome pith parenchyma in Figure 7.4 exhibits a deformation of the vesicular matrix. The deformation indicates that the rhizome was probably charred whilst fresh and results from the expansion of moisture during heating and escape of steam (Hather, 1993).

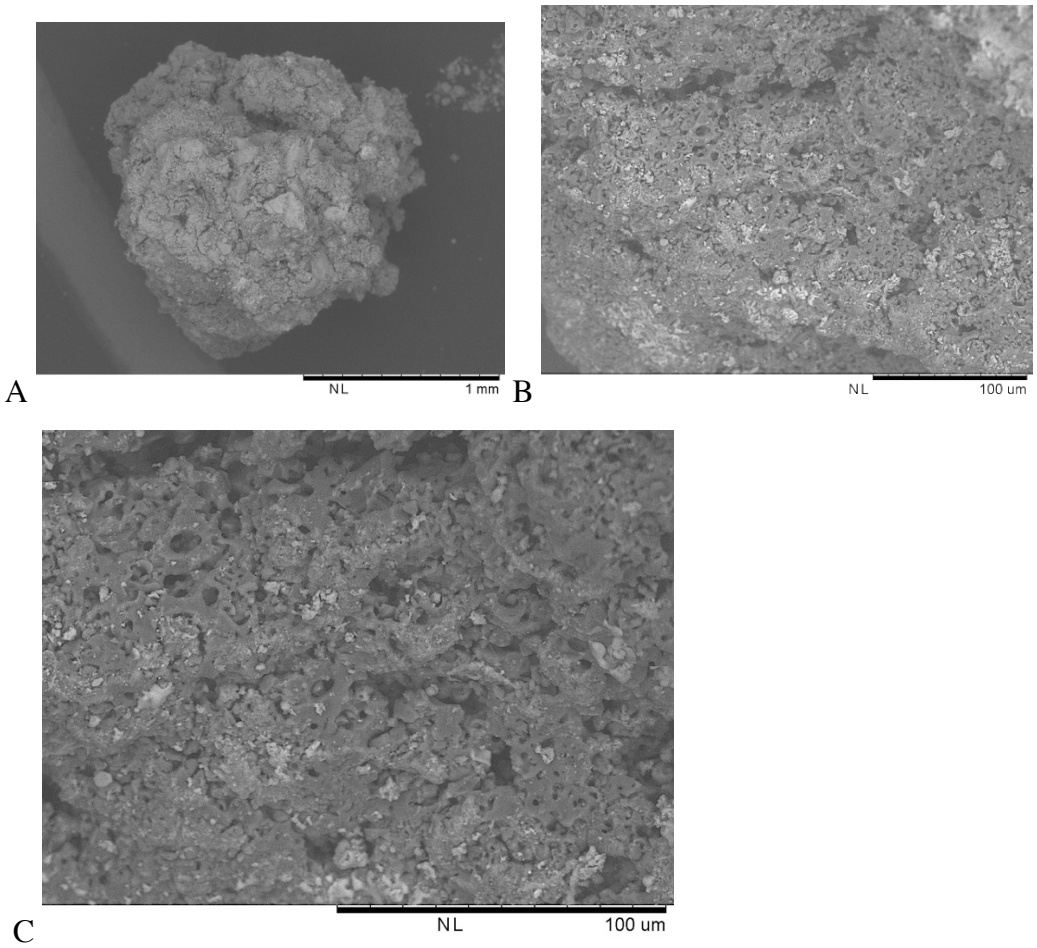


Figure 7.4: Fragment 53, Cave 1A Howiesons Poort phase, Klasies River shows: A: whole fragment; B: rhizome pith parenchyma; C: rhizome pith parenchyma vesicular matrix deformed by heating, identified from criteria described by Hather (Hather, 2000) (SEM micrographs lightened). (Micrographs: C. Larbey)

One of the key purposes of underground storage organs is to store water underground (geophytism), as opposed to storing water above ground (succulence) (Proches *et al*., 2006). The water content of most roots and tubers is high, *i.e*. 45%-81% in Asteraceae roots and tubers (Tertuliano and Figueiredo-Ribeiro, 1993) and 77%-89% in Liliaceae bulbs (Incoll *et al*., 1989). The high water content of a fresh rhizome would not make this a suitable source of fuel, so

rhizomes were probably being cooked for food. Additionally, the use of raw geophytes for moisture is common (Bergström and Skarpe, 1981; Van Wyk and Gericke, 2000).

Fragment 5, Sample 1 - Cortex

Heat has thickened the cell walls of fragment 5 but the cortex is visible, together with the collenchyma and parenchyma of the ground tissue just under the cortex still visible in Figure 7.5. There is also a relict vascular bundle, and its proximity to the cortex suggests this may be a monocot stem.

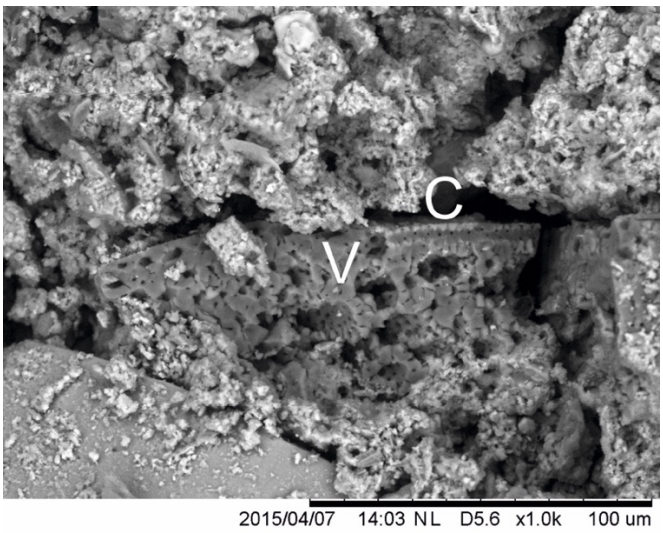


Figure 7.5: Fragment 5, Cave 1A, Howiesons Poort phase, Klasies River: shows parenchyma and collenchyma under cortex (under C) and relict vascular bundle as in the semi-circular tube shape under V. (Micrograph: C. Larbey)

Fragment 14, Sample 1 – Monocot stem parenchyma

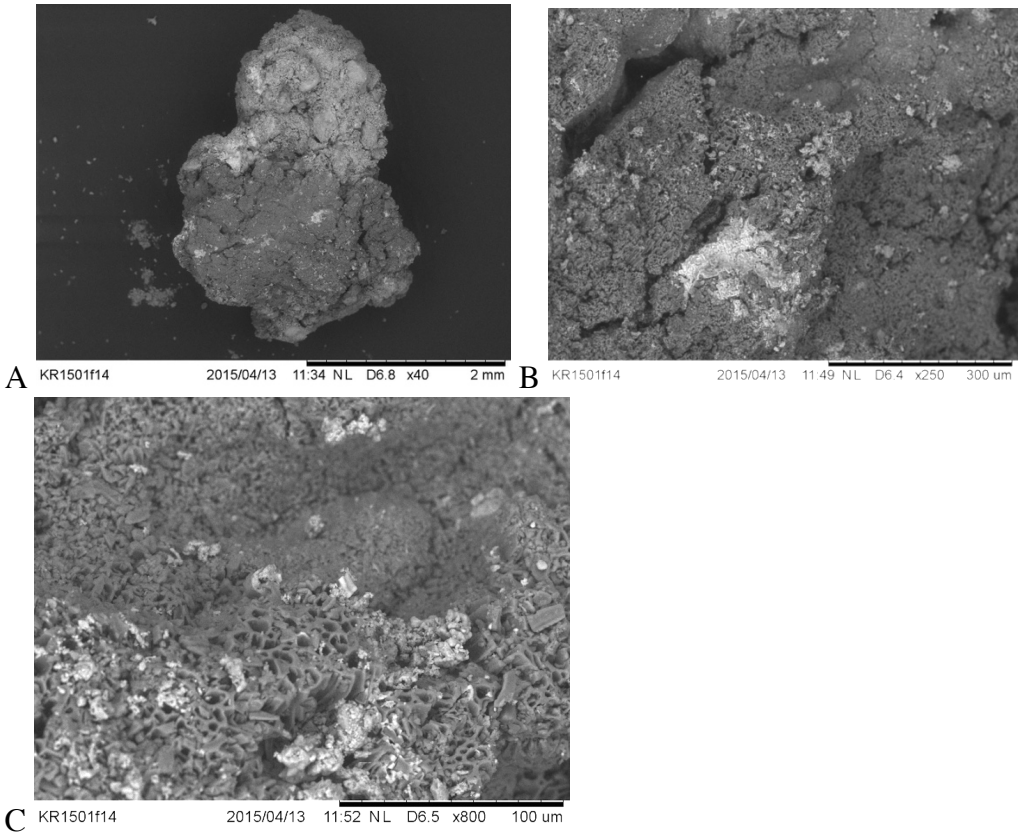


Figure 7.6: Fragment 14, Sample 1, Howiesons Poort, Klasies River A: whole fragment; B parenchyma and vascular bundles across fragment; C close up of vascular bundles and parenchyma (micrograph has been lightened). (Micrographs: C. Larbey)

Fragment 14 (Figure 7.6) shows the parenchyma and vascular structure and the rounded-cells of monocot parenchyma. It is not possible to determine the origin of this fragment of parenchyma but it seems likely to be a monocot rhizome.

Fragment 40, Sample 1- Fused parenchyma

Fragment 40 indicates fused parenchyma, characterised by the cells having a collapsed look which is caused by heating (Figure 7.7). This fragment also exhibits secondary root xylem, which is formed when a root undergoes a second season of growth (Hather, 2000). No vascular tissue is visible within the parenchyma suggesting this may be a fleshy taproot.

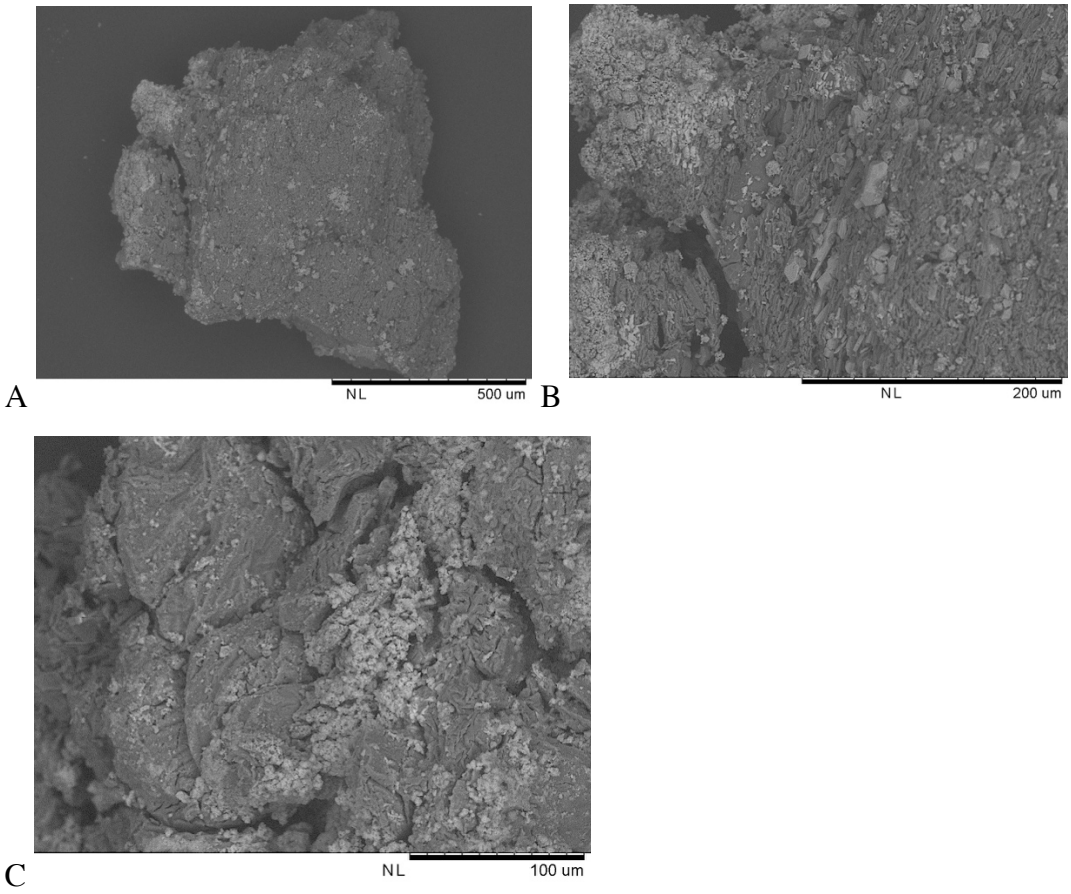


Figure 7.7: Fragment 40, Sample 1, Howiesons Poort, Klasies River. A = whole image of fragment 40; B = secondary root xylem; C = fused parenchyma probably from fleshy root. (Micrographs: C. Larbey)

Fragment 46, Sample 1 – Apical bud

Fragment 46 shows the vascular structure of an apical bud found on rhizomes. Parenchyma is not visible, although this may be part of the disrupted tissue surrounding the vessels (Figure 7.8).

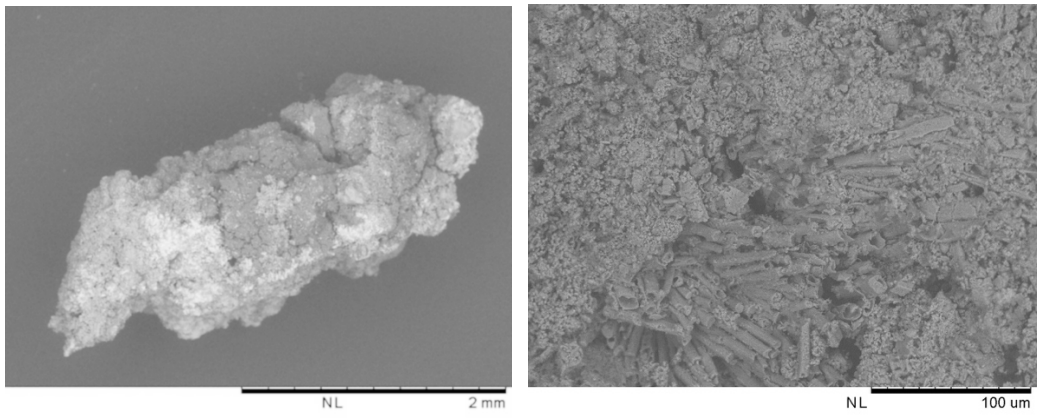


Figure 7.8: Fragment 46, Sample 1, apical bud, Howiesons Poort, Klasies River. Left: whole image of fragment 46 (micrograph lightened); right: vascular structure of apical bud identified from comparison with a Cyperaceae species apical bud in (Hather, 1993)). (Micrographs: C. Larbey)

Apical buds are found frequently on most below-ground stem storage organs and they either grow to form new storage organs or, in sympodial systems, may also go on to develop into leaves or inflorescences (Hather, 2000).

Fragment 15, Sample 1 – Druse crystal

Fragment 15 also exhibits indirect evidence of parenchyma and starchy plants. The presence of a multi-faceted druse crystal surrounded by fused, glass-like, parenchyma indicates a starchy plant fragment (Figure 7.9). Hather comments that druse crystals are preserved well by charring and "… in parenchyma that has become solid and glassy, will be visible embedded in otherwise featureless tissue." (Hather, 2000).

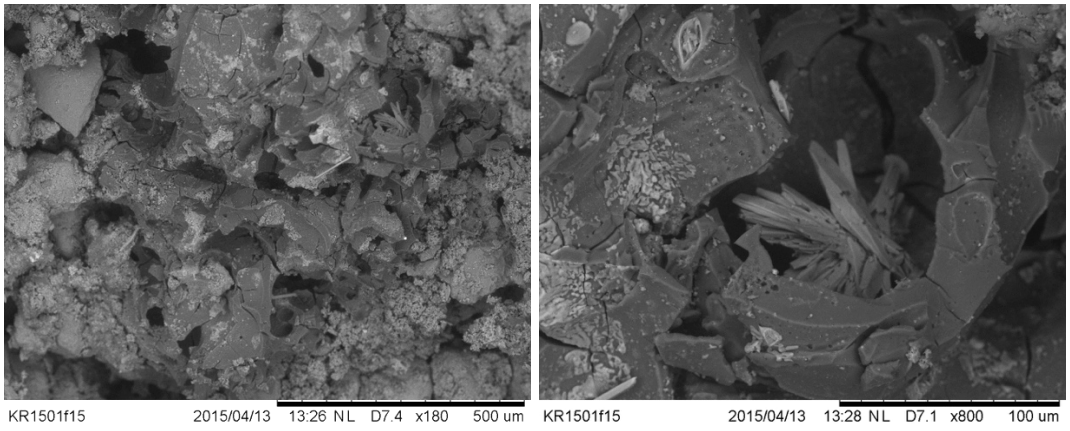


Figure 7.9: Fragment 15, sample 1, druse crystal, Howiesons Poort, Klasies River. Left: fused parenchyma with druse crystal (micrograph lightened); right: druse crystal within fused parenchyma zoomed-in image. (Micrographs: C. Larbey)

Druse crystals are made up of short, multi-faceted crystals formed from a central point. Although druse crystals can be found in leaves and other plant organs, these are usually small, around 5-25 μm in diameter (Franceschi, 2001; Hather, 2000). The druse crystal in Figure 7.9 is 70-78 μm, suggesting this may have come from a large rhizome or tuber. Druse crystals are known to form in the Araceae plant family (Franceschi, 2001) and around Klasies River in South Africa, the candidate for this could be *Zantedeschia aethiopica* (arum lily) that I found growing in Klasies River ravine whilst collecting for the reference collection for this research.

Fragment 9, Sample 1 – Monocot Stem

Fragment 9 included a monocot stem preserved by charring (Figure 7.10). The stem is hollow but with characteristic features of a monocot stem: there is a vascular bundle preserved at the fractured end and leaf internodes remain visible along the stem. This fragment offers evidence in support of the hypothesis that monocot plant tissue was cooked in this hearth.

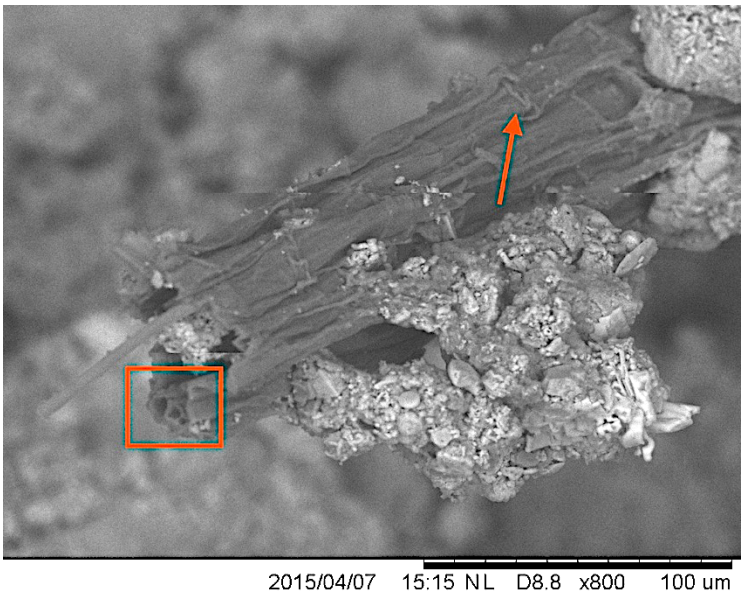


Figure 7.10: Fragment 9, sample 1, Howiesons Poort, Klasies River. This sample exhibits a hollow monocot stem, with a preserved monocot vascular bundle (in red square) and characteristic monocot internodes of which an example is pointed out by the red arrow. The fragment was encased in ashy matrix. (Micrograph lightened: C. Larbey)

Fragments 21, 16 and 51, Sample 1 - Secondary Root Xylem, Wood and Unid Plant Xylem

Plant xylem is a feature that occurs routinely throughout the assemblage; this section identifies how secondary root xylem and wood xylem are differentiated.

Secondary root xylem is formed primarily in angiosperms and is rare in monocots. It grows from vascular cambium in the second season. The appearance in roots differs from wood xylem (Figure 7.11).

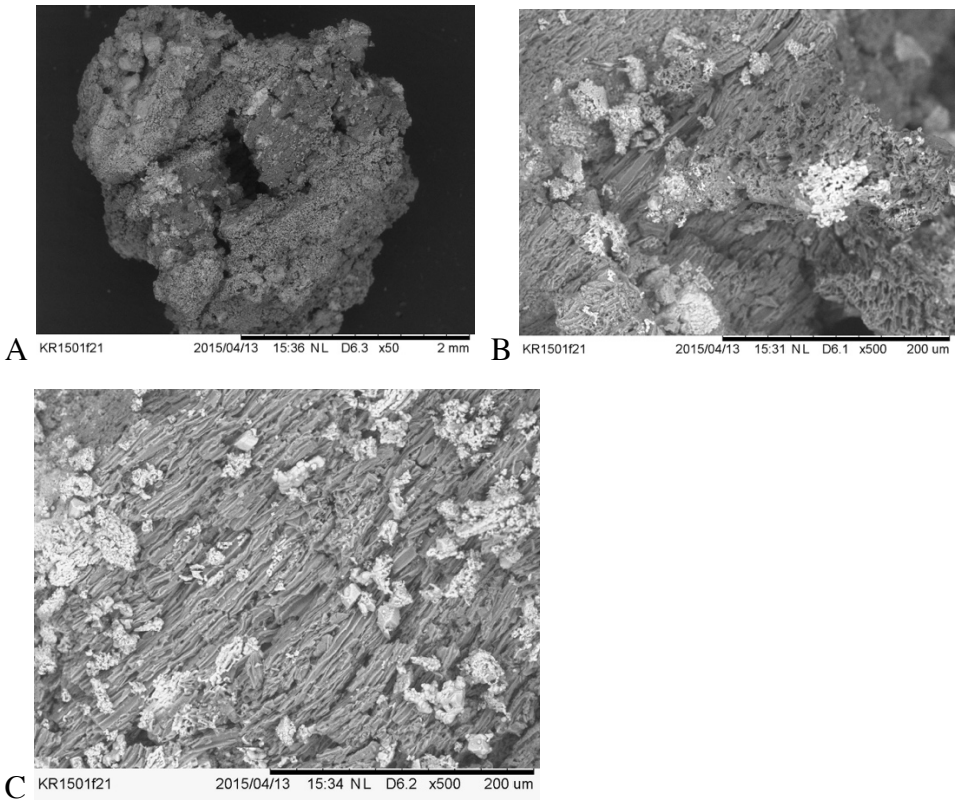


Figure 7.11: Fragment 21, sample 1, Howiesons Poort, Klasies River. Root xylem tissue: A = whole image; B = oblique transverse view of xylem tissue; C = transverse longitudinal section of secondary xylem, (micrograph lightened). (Micrographs C. Larbey)

In Figure 7.11C the xylem appears disordered and not continuous, which is a characteristic of secondary root xylem, especially compared to the wood structure in Figure 7.12. Wood xylem here is continuous and the charcoal has fractured along the plane of the xylem structure.

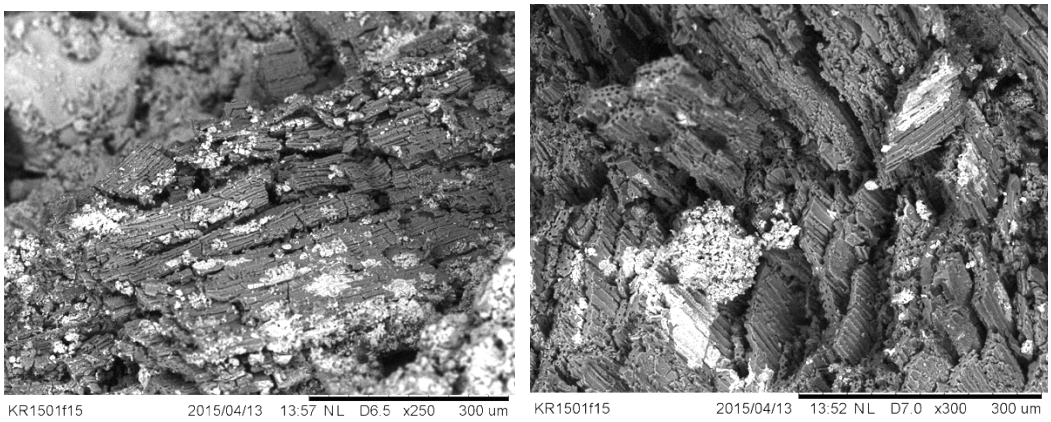


Figure 7.12: Fragment 16, sample 1, Howiesons Poort, Klasies River. Wood xylem: both images display continuous xylem structure more characteristic of wood. Note: The SEM label in Fig 7.12 mistakenly identifies Fragment 16 as Fragment 15. (Micrographs lightened: C. Larbey).

A large part of the unidentified category is comprised of unidentifiable vascular tissue of which fragment 51 at Figure 7.13 is an example.

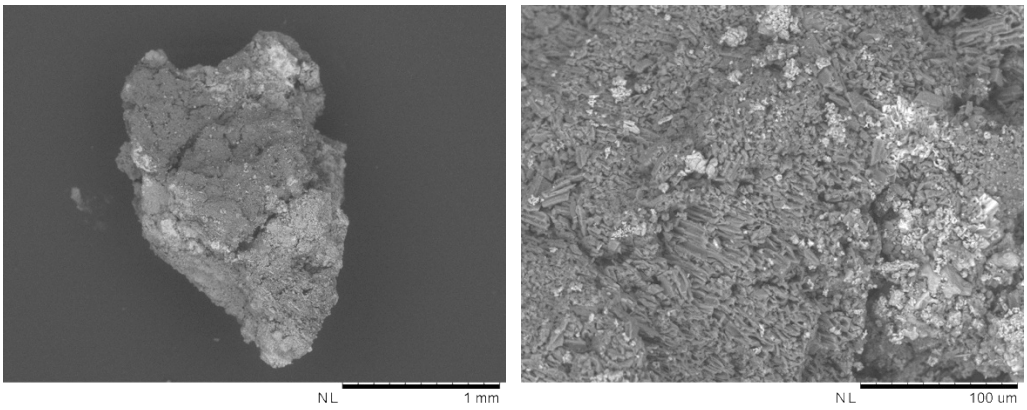


Figure 7.13: Fragment 51, sample 1, Howiesons Poort, Klasies River. Vascular tissue: left: whole image of fragment 51; right: unidentified xylem, possibly secondary root xylem, (Micrographs: C. Larbey).

Fragments 10, 39 and 25, Sample 1 - Unidentified Plant Tissue and Mixed Matter

The unidentified category also contains two further kinds of plant tissue. The first is those fragments that have poorly preserved or 'broken' plant tissue but where plant tissue is visible, for example the vascular bundle or the lumina (inter-cellular holes) in the images in Figure 7.14.

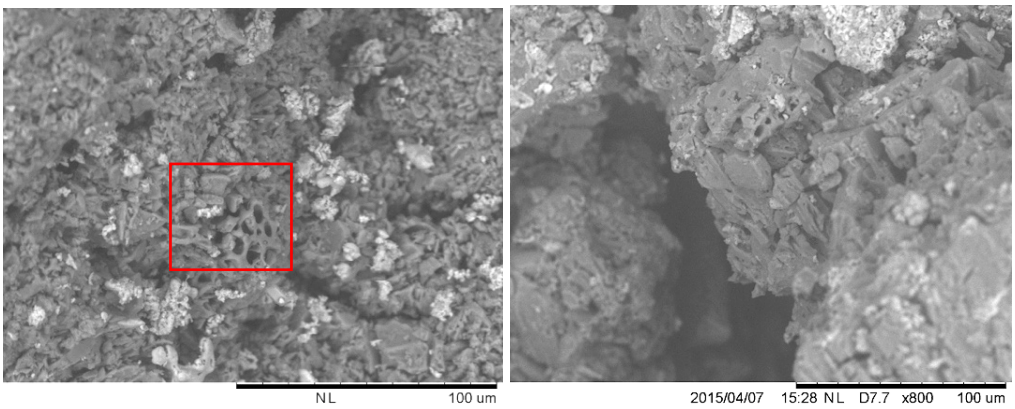


Figure 7.14: Fragments 39 and 10, sample 1, Howiesons Poort, Klasies River. Examples of broken tissue. Left: fragment 39: broken plant tissue with vascular bundle visible in centre in red box; right: fragment 10: possibly fused parenchyma with only the lumina visible but not sufficiently clear so categorised as unidentified. (Micrograph images lightened: C. Larbey).

The second is a category in need of further research, and that is finely 'mixed matter'. This is where plant matter is visible but broken and lying in many

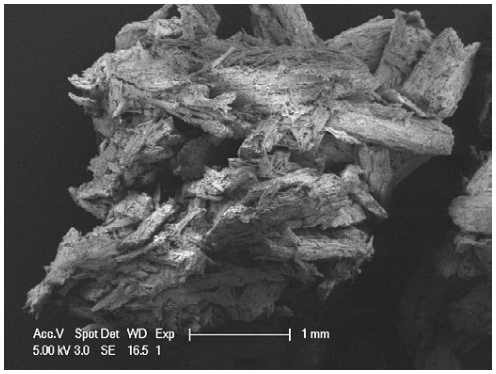
different directions, often in a mixed matrix; these fragments contain highly disordered material. The possibilities for this are:

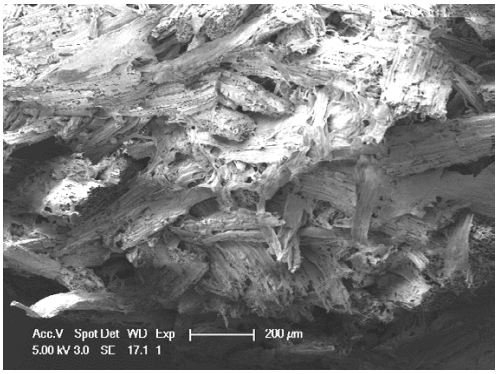
(a) human faecal matter, which is difficult to identify;

(b) burned children's faeces; Hillman first raised the possibility that finely ground plant foods were used for weaning infants from the discoveries made at Wadi Kubbaniya (Hillman, 1989). The archaeological evidence in this case came from charred finely comminuted faecal matter that was probably from infants, and was supported by ethnographic accounts of throwing infant faeces into the fire (Hillman, 1989). Hillman identified fragments of club rush tuber (*Scirpus* c.f. *tuberosus/maritimus*) in this plant matrix, supporting the possibility of pounding and cooking tubers for weaning. The ethnographic evidence for feeding infants on foraged foods that are either pre-chewed (Han *et al*., 2016) or processed in some way is widespread (Barnard, 1992; Crittenden *et al*., 2013; Hames, 1984; Hill and Hurtado, 2009; Lee, 1978). This was also the conclusion of research into finely comminuted material at Dolní Věstonice II (Mason *et al*., 1994) (Figure 7.15C).

(c) burned chewed plant material, where a fibrous wad has been spat into the fire (quad) (Schnorr *et al*., 2015). This possibility was explored in experimental research with baked, ground, chewed and then burned bark from Scots Pine *(Pinus sylvestris*) (Figure 7.15A and 7.15B) (Pryor *et al*., 2013).

Pioneering research has already begun on cooked plant foods, examining archaeological breads and porridges from Çatalhöyük East (Turkey) and comparing this analysis with experimental research into the cell morphology of processed plant foods and the appearance of food matrices under an SEM (González Carretero *et al*., 2017).

A 

B 

C 

Figure 7.15: Examples of experimental and archaeological 'mixed matter'. A and B: experimental processing of the bark of *Pinus sylvestris* (Scots Pine), which was processed by baking, grinding, chewing and charring (Image taken from Pryor *et al*., 2013: 979). C: 'Mush' from infant faeces. (Mason *et al*., 1994: 53).

However, none of these images compares well with the mixed matter fragments in this assemblage (Figure 7.16). The fragments of plant material appear to be too small for chewing, as per the experimental example in Figures 7.15A and B, yet are not the smooth texture of the proposed infant faeces of Figure 7.15 C.

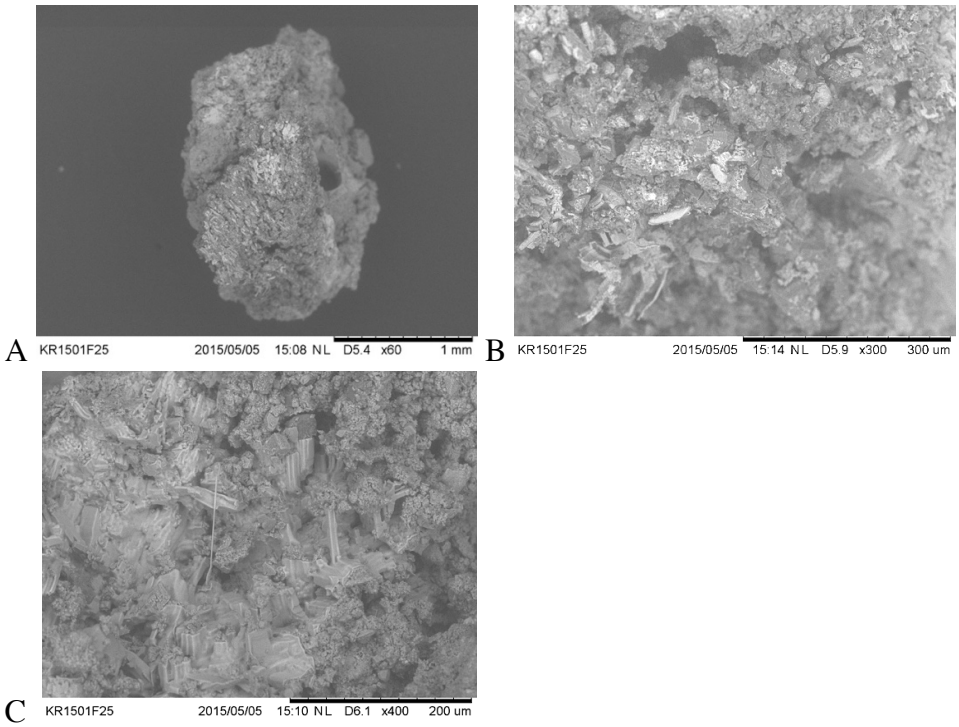


Figure 7.16: Fragment 25, sample 1, Howiesons Poort, Klasies River. Example of mixed matter. A – whole image of fragment 25; B = mixed matter; C = mixed matter with substance over part of matter from the same fragment,. (Micrographs lightened: C. Larbey)

These fragments have been counted in the 'unidentified' category although labelled 'mixed matter' for the sake of future research.

Sample 2

From: F50, Levels 15-17, East Face, Top Cutting, Howiesons Poort Phase

This sample was taken from the same hearth as sample 1 but from the left hand side base of the micromorph scar. The aim of the sample was to provide data from the edge of the hearth as opposed to the centre of the hearth as in sample 1.

Botanical Remains from Sample 2.

Table 7.3: Botanical results from sample 2, F50, Levels 15-17, East Face, Top Cutting, Cave 1A, Klasies River.

No. Fragments	Category
21	Parenchyma
16	Wood charcoal
2	Mixed matter
15	Unid plant tissue
54	Total

Fragment 1, Sample 2 - Parenchyma

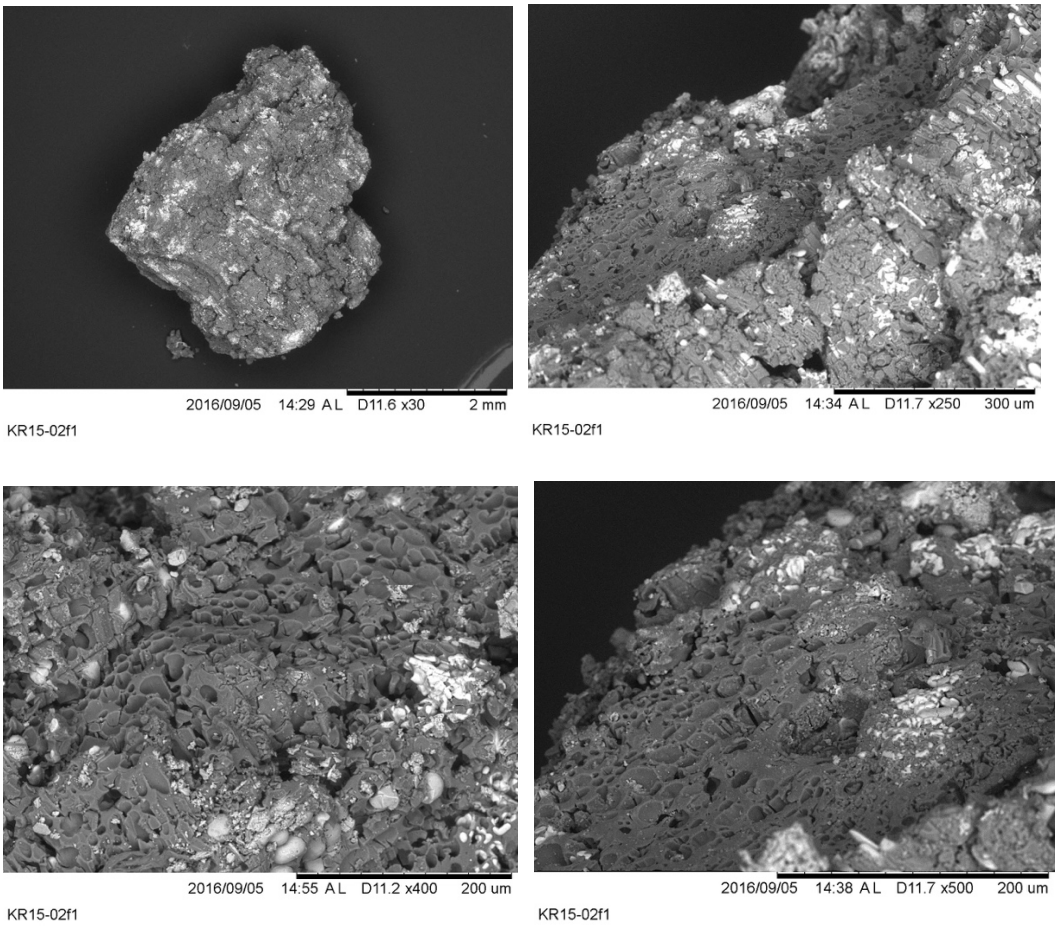


Figure 7.17: Parenchymous tissue forms the whole of fragment 1, sample 2 from the Howiesons Poort phase, Cave 1A, Klasies River. (Micrographs: C. Larbey)

There are no characteristics in fragment 1 to indicate the origin of this parenchyma (Figure 7.17). Most of the fragments were similar to this, and whilst definitively parenchyma, there were few characteristics. The parenchyma tissue has thickened through carbonisation and retained some of its original cell structure, although parts of the fragment have fused.

Fragment 2, Sample 2, - Taproot

Fragment 2 indicates a central vascular structure suggestive of a taproot (Figure 7.18). Although disrupted, the transverse longitudinal section (TLS) appears to have cut through both the xylem and parenchyma.

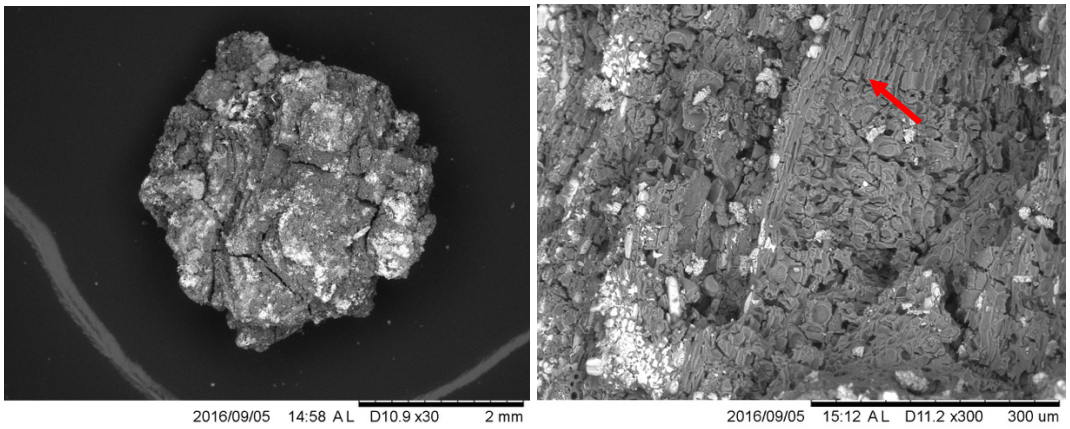


Figure 7.18: Parenchyma from fragment 2, sample 2, Howiesons Poort phase, Cave 1A, Klasies River. The image on the right exhibits a TLS view of parenchyma and xylem parenchyma, suggestive of a taproot (Hather 2000). (Micrographs: C. Larbey)

Fragment 15, Sample 2 – Root Tuber

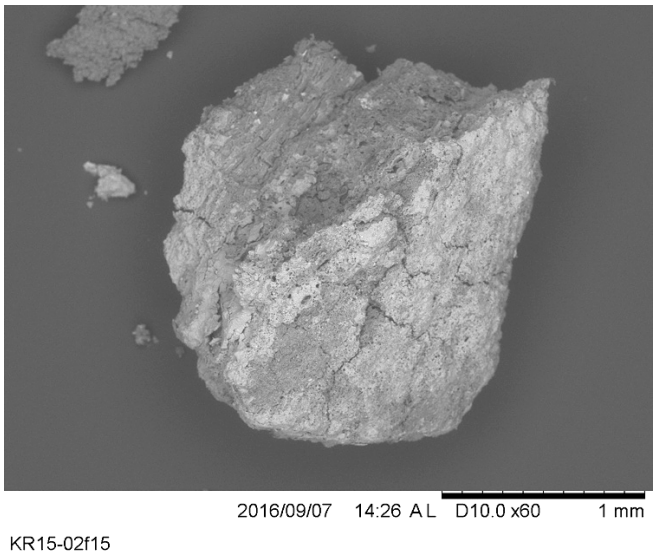


Figure 7.19: Whole image of fragment 15, sample 2, Howiesons Poort phase, Cave 1A, Klasies River. (Micrograph (lightened 19%): C. Larbey)

Fragment 15 has fractured obliquely across the transverse longitudinal (TLS) plane and although the stele has not preserved, the vascular and parenchyma tissue are still visible (Figures 7.19 and 7.20). The central xylem indicates that this is a root tuber (Hather, 2000).

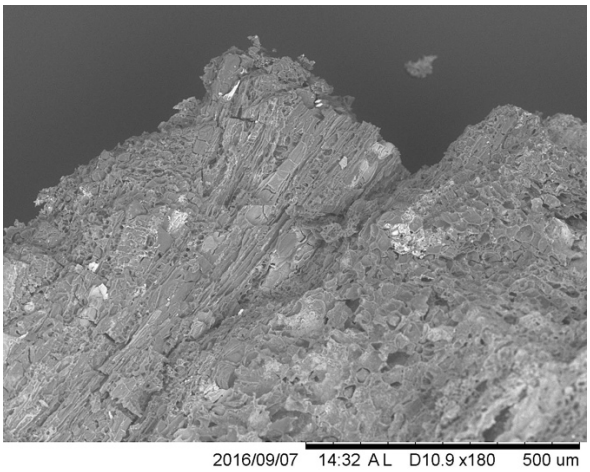


Figure 7.20: Fragment 15, sample 2, Howiesons Poort, Klasies River: exhibits oblique TLS of a root tuber with xylem and parenchyma but stele not preserved. (Micrograph: C. Larbey)

Fragment 44, Sample 2, - Wood

Three fragments showed transverse section views (TS) of wood that, without the TLS or radial longitudinal section (RLS) views, cannot be identified definitively but which compare favourably with the *Searsia undulata* identified by Caroline Cartwright in the MSA Still Bay phase of Diepkloof Rockshelter, South Africa (Cartwright, 2013). The Still Bay phase is broadly coeval with the Howiesons Poort phase at Klasies River.

Although *Searsia undulata* is not indigenous to the Eastern Cape, other species of *Searsia* are found in this region (Figure 7.21).

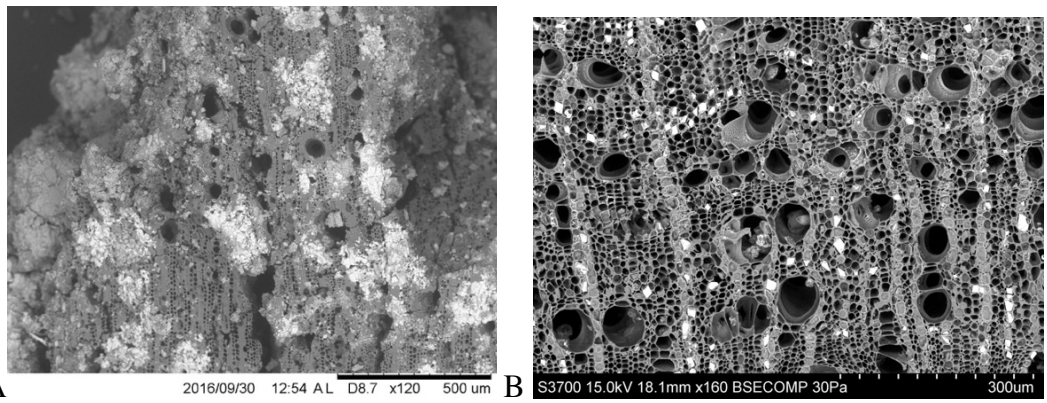


Figure 7.21: Fragment 44, Howiesons Poort, Klasies River: putative identification of wood species, *Searsia* sp. A: Fragment 44 TS view exhibits the varied pattern of vessels seen in B: *Searsia undulata*. (Micrograph left: C. Larbey, and micrograph right: Cartwright (2013: 3471).

Searsia is a species associated with Albany thicket and is present around the site today. Its presence at Klasies River during the MSA would be consistent with the vegetation described by Yvette van Wijk (van Wijk *et al*., 2017).

Sample 3 – Off Hearth

From: F50, Levels 15-17, East Face, Top Cutting, Howiesons Poort Phase

Botanical results from sample 3 (from the debris layer to the left of the hearth)

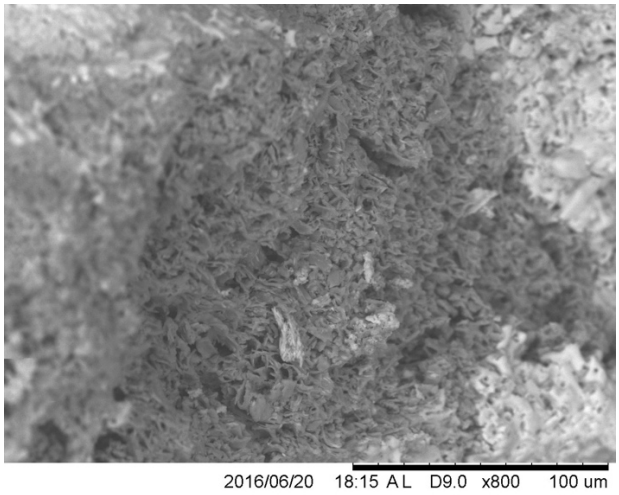
There were few botanical remains from this sample and of the eleven starchy plant fragments, seven were fused parenchyma (Table 7.4). Two fragments are exceptional in that they suggest for the first time, the use of rhizomes from aquatic/semi-aquatic plants.

Table 7.4: Botanical results from sample 3, F50, Levels 15-17, East Face, Top Cutting, Cave 1A, Klasies River

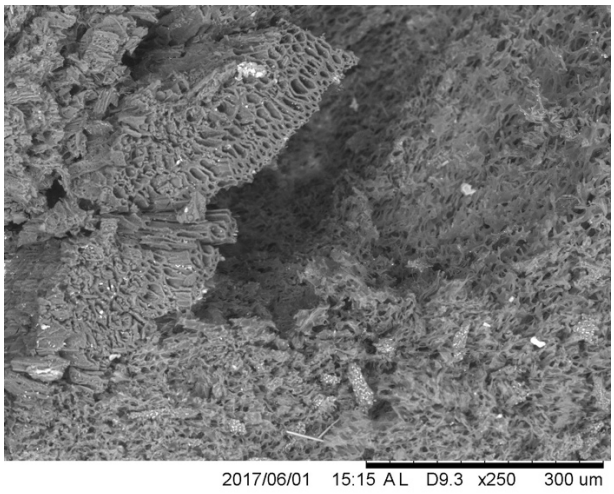
No. Fragments	Category
4	Parenchyma
7	Fused starch
20	Unid plant tissue
4	Wood charcoal
38	Total

Fragments 22 and 27, Sample 3 – Aquatic and semi-aquatic plant remains

Aquatic and semi-aquatic species such as water lilies and reeds have aerenchyma as the cortex and the stele comprises the parenchymous tissue (Hather, 2000). The archaeological fragment at Figure 7.22A exhibits the starchy parenchyma in the pith and the cortex has not preserved so it is not possible to identify to species. However, there is a similarity between the archaeological fragment and the *Juncus puuctorius* (reed) sample from the modern reference collection made for this research (Figure 7.22B). *Juncus* sp. are found both in Klasies River ravine area and in a fresh water pond close to the main cave today.



A



B

Figure 7.22: Pith Parenchyma of semi-aquatic plants. Fragment 22, sample 3, Howiesons Poort, Klasies River. Example of pith parenchyma from Juncaceae species. A: fragment 22 from sample 3 exhibits the 'feathered' effect of starchy pith that compares favourably with B: the pith parenchyma of the *Juncus puuctorius* (Juncaceae) reed, from the modern reference collection from around Klasies River. (Micrographs: C. Larbey)

Fragment 27, Sample 3 - Aerenchyma

This fragment exhibits the characteristic isodiametric cell pattern of aerenchyma but the stele is not visible (Figure 7.23).

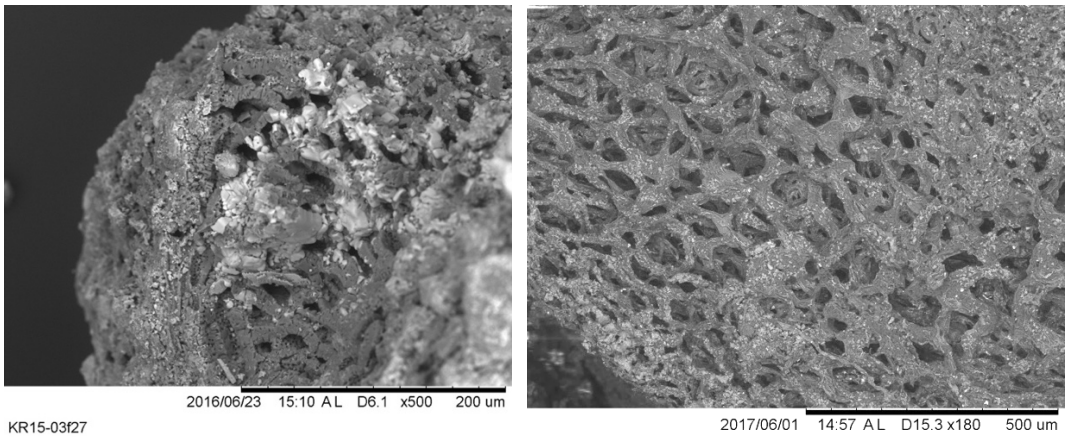


Figure 7.23: Aerenchyma. Fragment 27, sample 3, Howiesons Poort, Klasies River: archaeological aerenchyma compared with aerenchyma from the reference collection. Left: whole image of fragment 27, sample 3: right: aerenchyma cells displaying an isodiametric type two pattern of cells from modern parenchyma reference collection, (see Hather 2000: 36). (Micrographs: C. Larbey)

Fragments 24, 28 and 29 – Fused Parenchyma

Several of the fragments were composed of fused or glass-like parenchyma (Figure 7.24). Parenchyma can sometimes become solid (fuse) through the charring process, leaving a vitreous or glass-like appearance (Hather, 2000). Whilst this destroys many characteristics, it can leave relict vascular tissue visible.

MSA I Phase, Cave 1

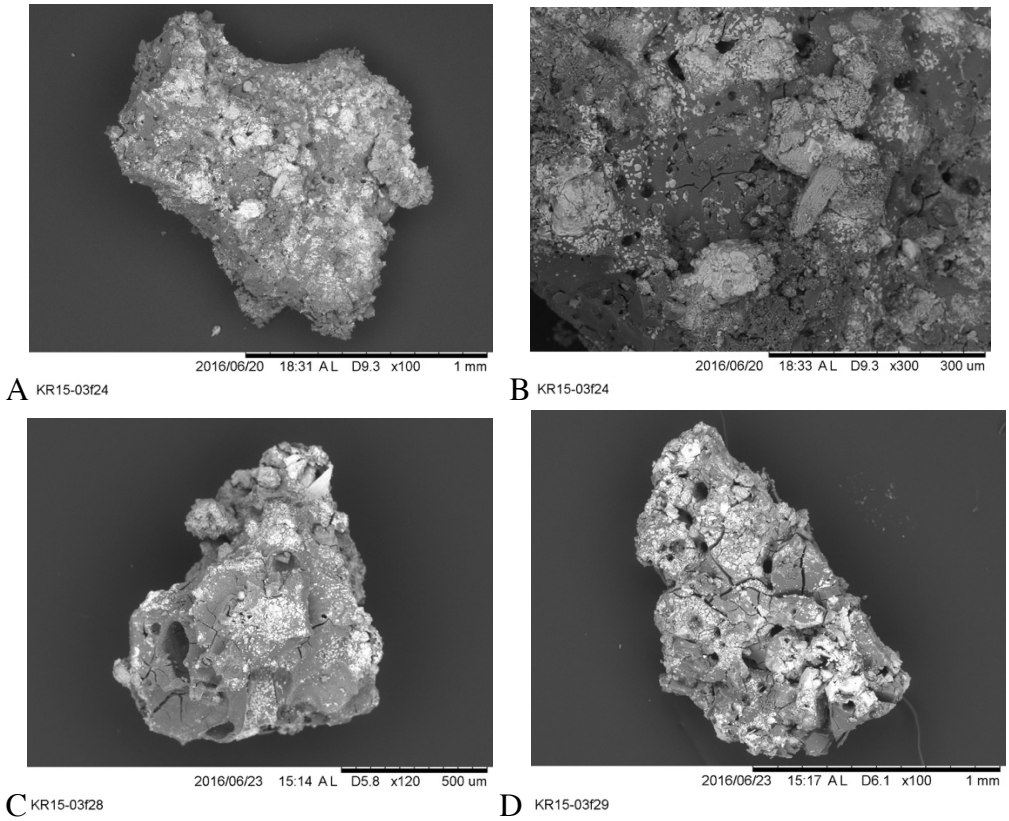


Figure 7.24: Fused Parenchyma. Fragments 24, 28 and 29, sample 3, MSA1, Klasies River: examples of fused parenchyma. A: whole image of fragment 24; B: fused parenchyma of fragment 24; C: fragment 28 fused parenchyma; D: fragment 29 fused parenchyma. (Micrographs: C. Larbey)

The level of fusing and preservation of tissue is not dependent upon species but associated with high levels of water, oil or sugar content prior to burning (Hather, 2000).

Sample 4

From Levels 38-39, South Face, Witness Baulk, Cave 1

This sample came from the hearth just above bedrock so represents the oldest hearth from Klasies River. Although the sample was taken as an untrowelled block, the sediment was loose and friable and it was not possible to preserve the integrity of the stratified layers within block. The preservation was poor and there were few remains from this hearth, with some vertebrate remains but no lithics. Of the plant remains many fragments were inconclusive. Butzer suggested sea incursion into the cave during this early period and this may explain the poor preservation (Butzer, 1982).

Botanical results from Sample 4:

Table 7.5: Botanical results from sample 4, Levels 38-39, LBS member, South Face, Witness Baulk, Cave 1

No. Fragments	Category
1	Parenchyma
3	Secondary root xylem
8	Unid plant tissue
3	Raphides, styloid and rhomboid crystals
15	Sediment
30	Total Fragments

Fragment 1, Sample 4

Fragment 1 is a rhizome fragment, exhibiting parenchyma, a vascular bundle, including phloem, and secondary xylem (Figure 7.25).

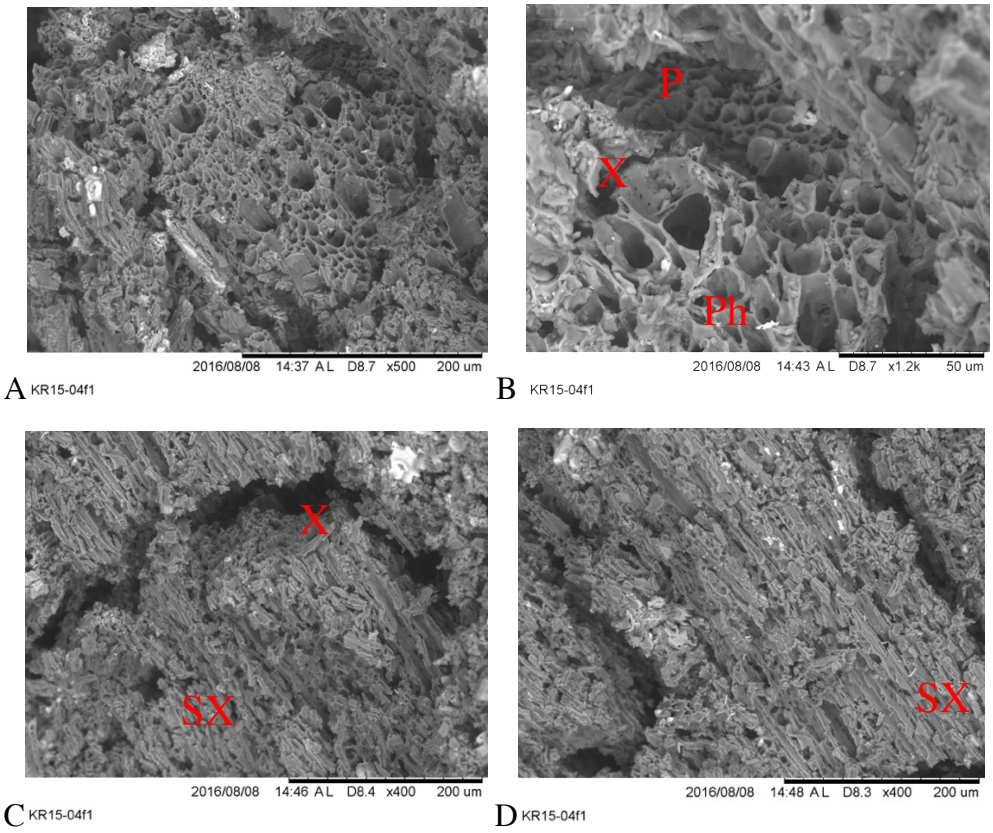


Figure 7.25: Fragment 1, sample 4, MSA1, Klasies River: rhizome parenchyma and vascular bundles. A: vascular bundle and parenchyma; B: P = parenchyma, X = xylem, Ph = phloem, SX = secondary xylem. (Micrographs: C. Larbey)

The vascular tissue indicates secondary root growth in fragments 19 and 31, with fragment 19 in TLS in Figure 7.26A and fragment 31 in TLS and TS in Figures 7.26B, 7.26C and 7.26D. This would suggest a fleshy taproot and compares favourably with Hather's *Pastinaca sativa* (Hather 1993: 72). This evidence supports the hypothesis that early humans were cooking fleshy roots for food from the earliest occupations at Klasies River.

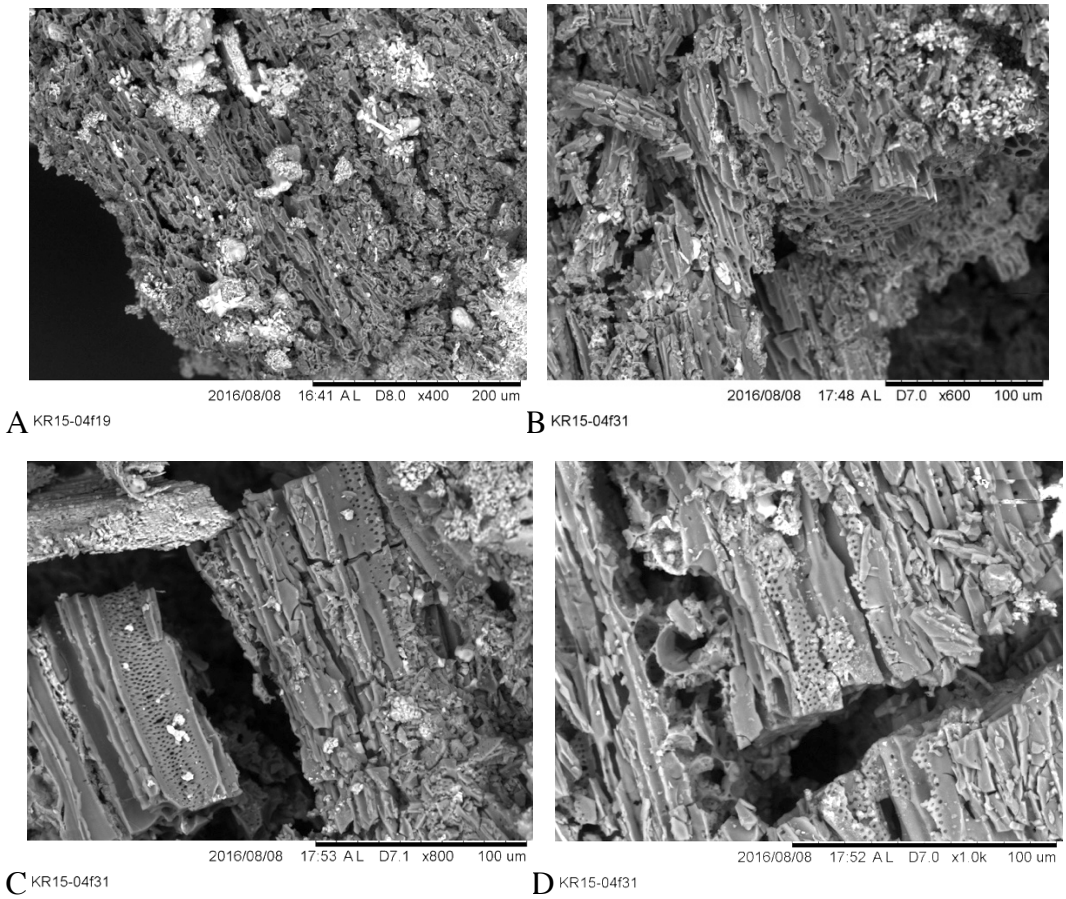


Figure 7.26: Fragments 19 and 31, sample 4, MSA1, Klasies River: exhibit secondary root xylem, parenchyma and vascular bundle. A: Fragment 19 exhibits secondary root xylem; B: Fragment 31 exhibits secondary xylem with tracheids, xylem parenchyma and the cut base of a vascular bundle; C: Fragment 31 vessels with alternate pitting in the secondary xylem; D: Fragment 31 secondary xylem .(Micrographs lightened: C. Larbey)

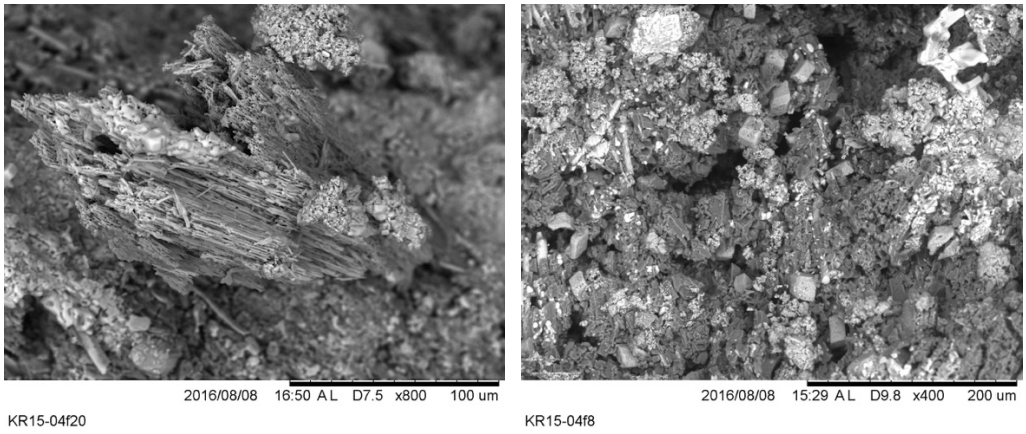


Figure 7.27: Raphide and rhomboid crystals in fragments 20 and 8, sample 4, MSA1, Klasies River. Left: fragment 20 exhibits a raphide crystal bundle in an unidentified plant matrix; right: fragment 8 exhibits rhomboid crystals in this broken unidentified plant matrix. (Micrographs: C. Larbey)

The fragments that survived from this hearth context appear to be entirely fleshy taproots, with proxy indicators of the presence of starch in the form of raphide and rhomboid crystals (Figure 7.27). As described in Chapter 3, calcium oxalate crystals are common in underground storage organs, with occasionally more than one type identified in the same plant. Although they are found in leaves, when combined with fused parenchyma they can be proxies for starchy plants.

Sample 5

From Levels 38-39, South Face, Witness Baulk, Cave 1

This hearth was 25cm above bedrock but still within the light brown sand member (LBS).

Botanical results from sample 5, see Table 7.6.

In this layer, as with sample 1, it was possible to separate the findings from the ash layer from the debris layer beneath. However, as the micromorphology findings show, the ash layer represents a number of burning events, which were not visible at the time of screening this sample.

Table 7.6: Botanical results from sample 5, Levels 38-39, LBS member, South Face, Witness Baulk, Cave 1

No. Fragments	Category
Ash Layer	
5	Parenchyma
2	Disrupted parenchyma
4	Fused parenchyma
11	Wood
2	Mixed matrix
33	Unid plant tissue
57	Total Ash Layer
Carbon-rich Layer	
5	Fused parenchyma
42	Wood
2	Mixed matrix
41	Unid plant tissue
90	Total Carbon Layer

Fragment 4, sample 5 – Stem Tuber

Fragment 4 is a large (6.2mm wide x 4.3mm deep) fragment of well-preserved parenchyma, exhibiting only slight cell deformation from heating (Figure 7.28A). Figure 7.28B shows clearly the parenchyma. Fragment 4 demonstrates also demonstrates how some views can be misleading. Figure 7.28C shows deformed cortex parenchyma and fused parenchyma of fragment 4 that appears to be poorly conserved. A close-up of cell lumina can be seen in the parenchyma of Figure 7.28D.

Parenchyma in Figures 7.28E and 7.28F show that the parenchymous cells are thickened by carbonisation and the monocot characteristics of the vascular bundle in this fragment suggest this may be a stem tuber (Hather, 1993).

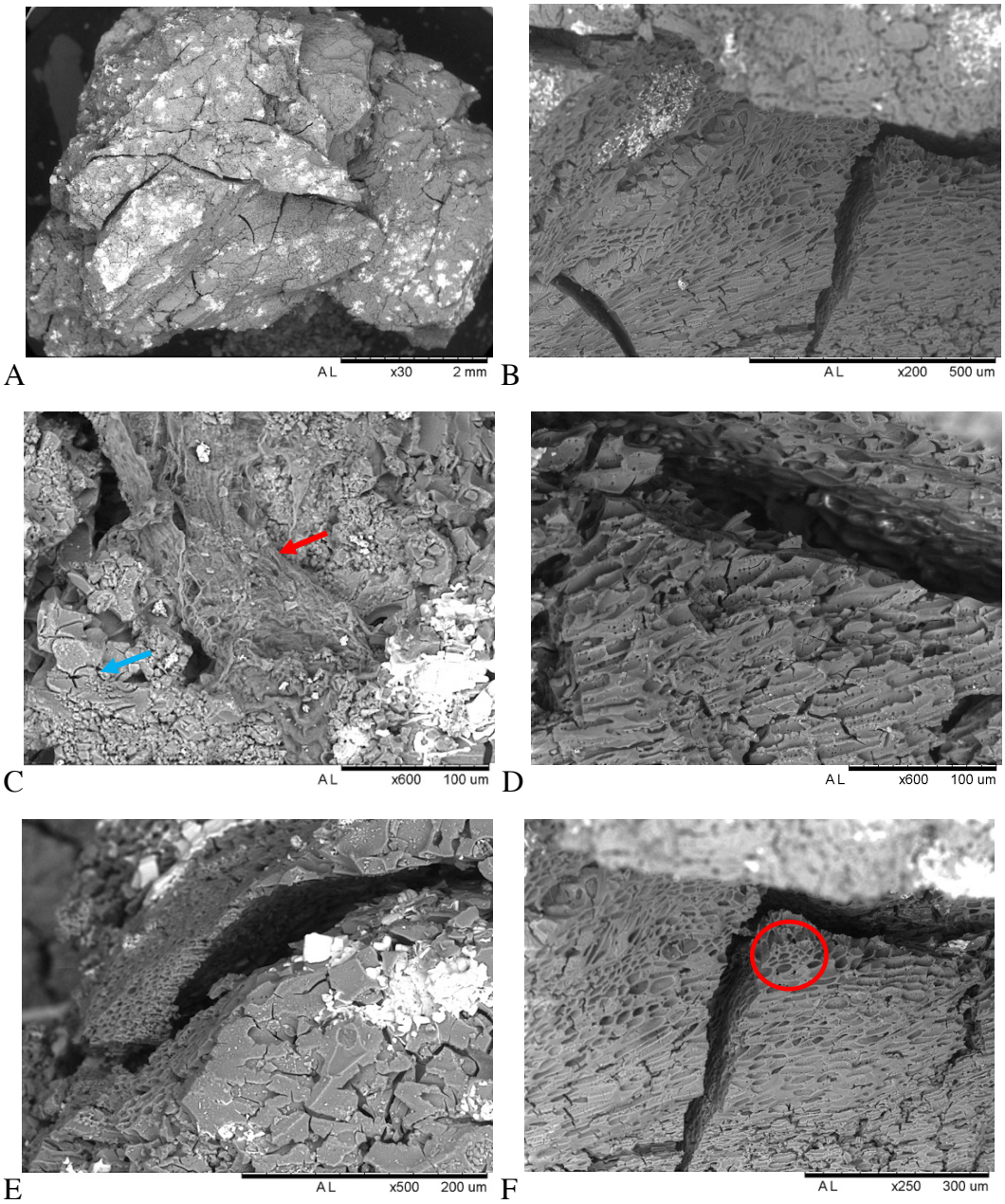
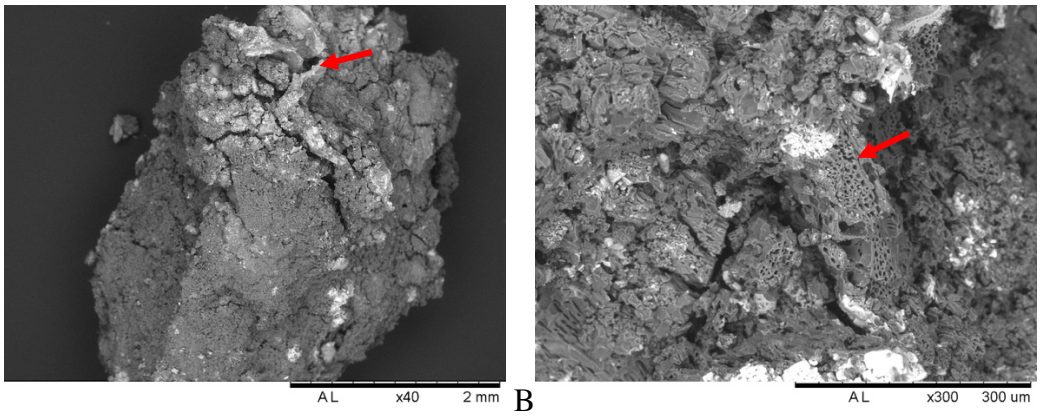


Figure 7.28: Fragment 4, sample 5, MSA1, Klasies River: exhibits well-preserved parenchyma. A: whole fragment 4; B: parenchyma; C: exhibits deformed cortex parenchyma (red arrow) and fused parenchyma (blue arrow); D: parenchyma with lumina (holes) in each cell; E: fragment 4 exhibits rounded parenchyma and in the foreground fused parenchyma; F: further parenchyma with lumina and monocot vascular bundled (red circle). (Micrographs: C. Larbey)

Fragment 5, Sample 5 – Root Tuber

Despite poor preservation, distinct characteristics of a root tuber vascular bundle preserved by fused starch (carbon) and identified from (Hather, 1988; Hather,

2000) can been seen in Figure 7.29. Again this fragment is not small, measuring 4.9mm x 3.1mm.



A B

Figure 7.29: Fragment 5, sample 5, MSA1, Klasies River: example of a root tuber. A: fragment 5 whole image with the epidermis of this root tuber visible (red arrow). B: the vascular bundle of this stem tuber is preserved as solid carbon (red arrow), derived from the phloem, (Hather 1993: 59 Figure 213). (Micrographs: C. Larbey)

Monocots seem to be prevalent in this sample with fragment 6 offering a number of characteristic features (Figure 7.30).

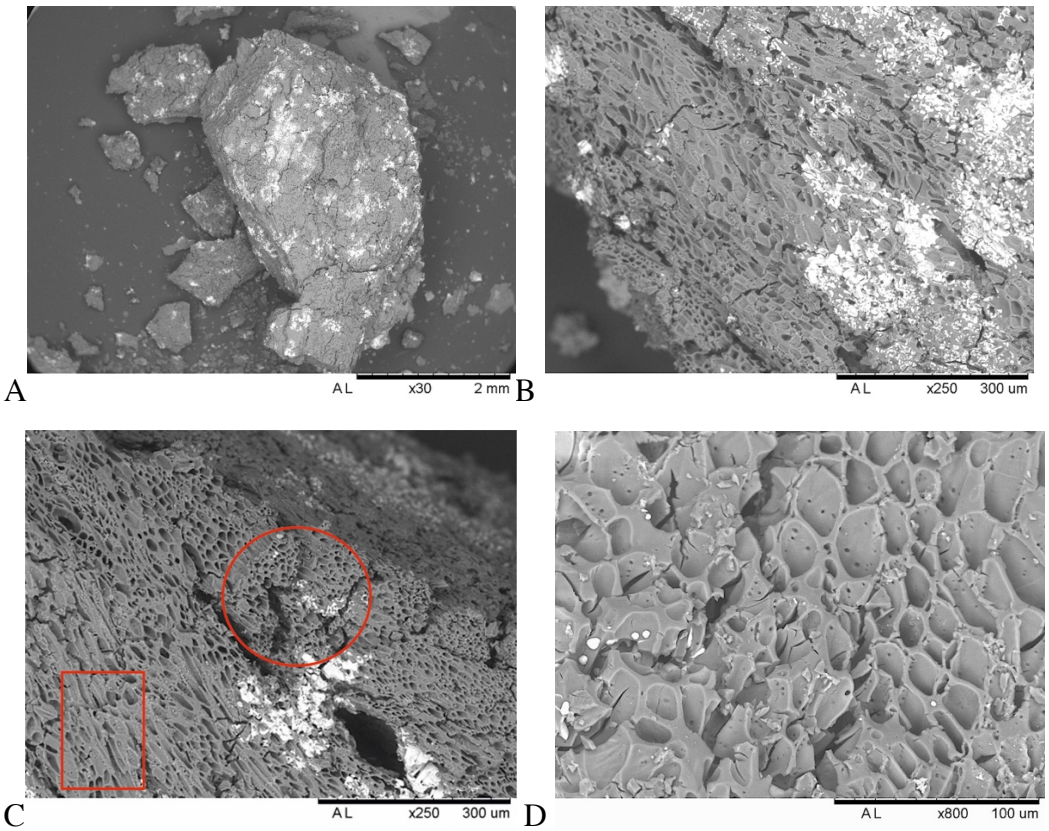
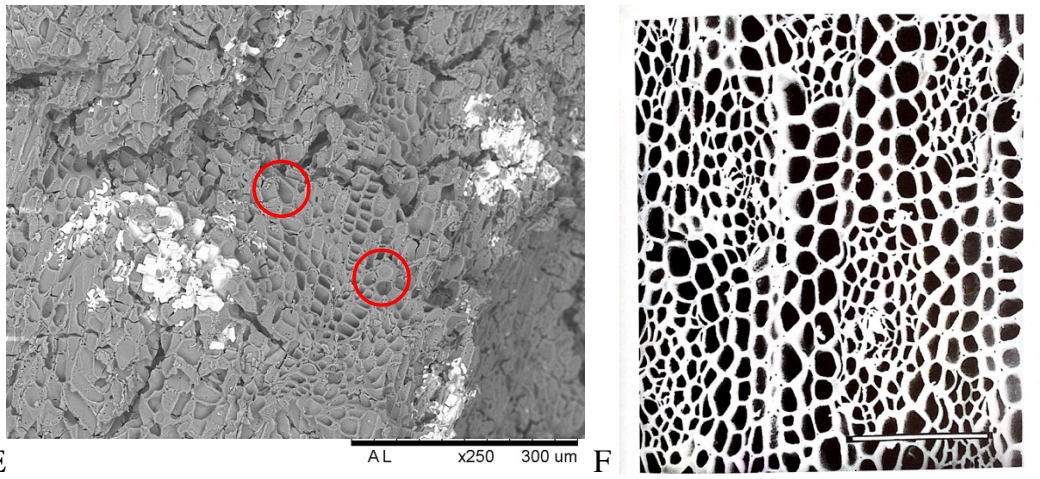


Figure 7.30: Fragment 6, sample 5, MSA1, Klasies River: monocot stem parenchyma. A: fragment 6, whole image (4.6mm x 2.7mm); B: parenchyma with lumina; C: oblique TS view showing monocot vascular bundles (red circle) and TLS view through parenchyma of secondary xylem (red box) identified from (Hather 2000: 28); D: close-up of intra-cellular lumina that appear regularly throughout the archaeological assemblage. (Micrographs: C. Larbey)

Figure 7.30C indicates vascular bundles identified in a number of monocot species (Hather, 1988; Hather, 1993). Conn and Giliham have suggested that the lumina or intra-cellular holes are associated with the flow of oxygen and/or water through the plant (Conn and Giliham, 2010). Lumina have not been discussed much in the literature and little evidence was found for their suggested function. The vacuole is the space in the parenchyma cell that is used for storage of starch granules, oils and waste materials, and lumina may also be associated with regulating the nutrition of the plant (Conn and Giliham, 2010). Their role in parenchyma does

not appear to be fully understood, with most lumen research focussing on their role in leaf cells (Conn and Giliham, 2010).

The cell structure in the transverse section of this fragment offers a rare possibility in this archaeological assemblage to identify a fragment to family. Fragment 6 also exhibits a distinct pattern in the TS section, with vessels, often almost rectangular, in two rows amongst monocot vascular bundles. Figure 7.31A offers a relict vascular and parenchyma structure that compares favourably with the Liliaceae family species identified by Hather at Figure 7.31B. However, Liliaceae is not a family common among Cape geophyte taxa, although there are 48 endemic geophytes species in the Liliales order to which this fragment may belong (Proches *et al*., 2006).



E F

Figure 7.31: Fragment six, sample 5, MSA1, Klasies River: indicates cell and vascular pattern that compares favourably with Liliaceae family. E: TS view of Fragment 6 exhibits double row of square vessels, with relict vascular bundles either side, circled in red, (Micrograph: C. Larbey); F: the image from (Hather 2000: 47) exhibits a similar structure except that all the vascular bundle cells are preserved and visible. This structure is identified as Liliaceae by Hather.

As Liliales is one of the orders associated with Greater Cape Floristic Region and available throughout areas of Fynbos and around Klasies River, it seems possible that this may be parenchyma from a species of that family.

Fragment 146, Sample 5 - Rhizome Parenchyma

Figure 7.32 exhibits the cell structure of pith parenchyma that has been heated whilst fresh, with the deformed vesicular matrix in Figure 7.32C caused by escaping moisture (Hather 2000).

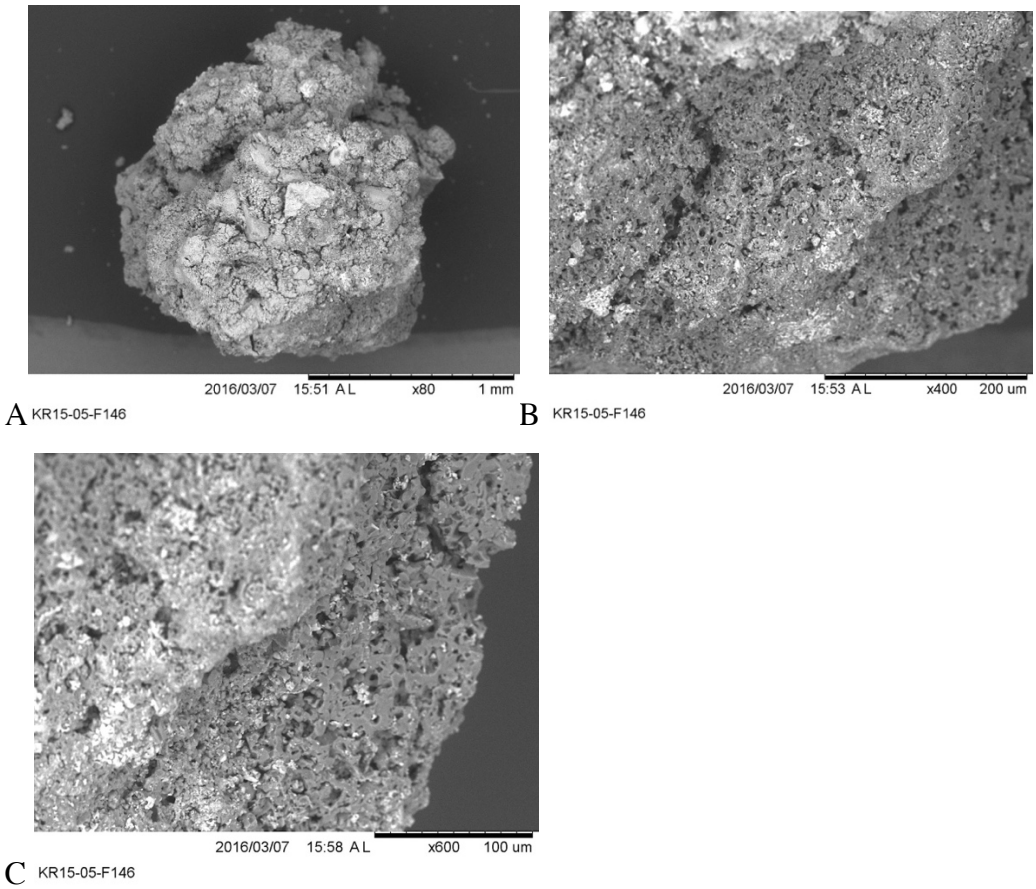


Figure 7.32: Fragment 146, sample 5, MSA1, Klasies River: rhizome parenchyma. A: whole image of fragment 146; B: rhizome pith parenchyma; C: close-up of rhizome pith parenchyma deformed cell structure. (Micrographs: C. Larbey).

Fragment 136, Sample 5 – Unidentified fibrous shrub

This fragment of fibrous fusiform (spindle-like) xylem and rays that look like beads in radial longitudinal section (RLS) is unique in this assemblage (Figure 7.33).

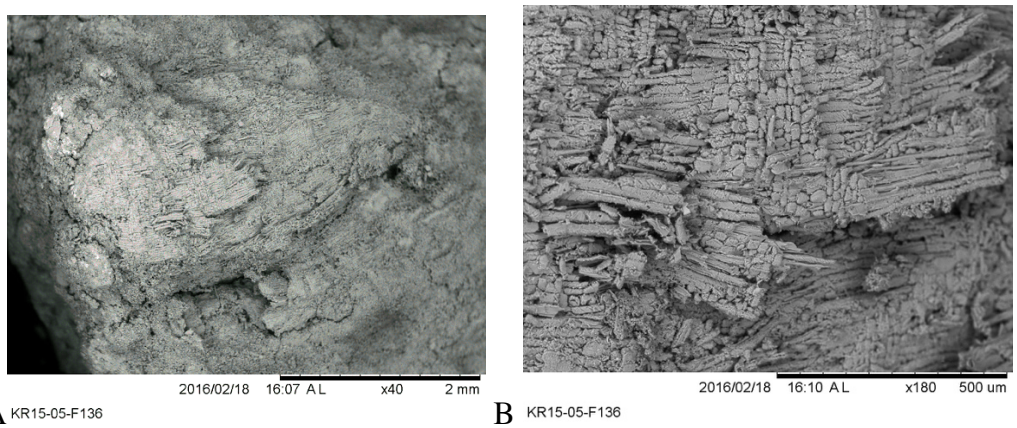


Figure 7.33: Fragment 136, sample 5, MSA1, Klasies River: unidentified fibrous shrub. A: whole image of fragment 136 (1.1cm x 0.9cm); B: RLS view of fragment 136 with rays giving a bead-like appearance and fusiform xylem with annular cell wall thickening in the tracheids. (Micrographs: C. Larbey).

There are three candidate shrubs for this fragment, *Carissa* sp., *Secamone* sp. and *Akocanthera* sp. All are indigenous to South Africa, ancient species, poisonous and used as medicines and poison for arrow tips, and all are found around Klasies River (van Wijk, 2018, Pers. Comm.). This requires further research as identification may be possible from these SEM micrographs.

7.2.4 Klasies River Density Analysis

The data for both site are non-parametric and the low number of data points prevents advanced statistical analysis. Tests for non-parametric data might include the Kruskal-Wallis test, which is a measure of scale data and the Chi Square test, used as a test of significance in spatial analyses. There were insufficient data points to run either test. The Chi Square test also requires that the data are independent, and this was not the case (Hawkins, 2009).

Density analyses have been conducted on the each of the samples from each location. Density analysis is a ratio based on the numbers of starchy plant fragments (parenchyma, secondary root xylem and selected crystals) per litre of sediment. The numbers have been adjusted where the sample volumes were below one litre and where only 50% of the sample was analysed.

These data show charred starchy plant remains are present in all of the hearth samples from Klasies River (Table 7.7 and Figure 7.34). They are also present in the off-hearth debris layer sampled in the Howiesons Poort layer (sample 3). The

density is highest in the sample taken from the edge of the hearth in the Howiesons Poort layer (sample 2); higher than the sample taken through the centre of the hearth (sample 1). It is recommended for future research that multiple samples are taken through different positions of the hearths.

Sample 4 exhibits a density that is below the off-hearth level. This low density may have a number of possible explanations. The preservation in this level was extremely poor and the organic remains density might be expected to be poor. Deflation of the ash in this hearth might also be an issue. However, the ash layers have numerous rhomboid-shaped aggregates of micro-crystalline carbonates, typical of wood ashes that suggest they have not been disrupted (Mentzer, 2016, Pers. Comm.). Also the various lenses within the layers that suggested multiple burnings are intact. These features would appear to rule out any hearth cleaning effect. It may be that fewer plant foods were cooked in this hearth.

Table 7.7: Klasies River Results Data.

Sample no.	Hearth Context	Phase	Total no. of plant fragments in sample	No. of starchy plant fragments in sample	Sample Volume (ml)	Density Analysis* (No. of starchy plant fragments/ litre sediment)
1	F50, 15-17	HP	57	16	300	53
2	F50, 15-17	HP	52	21	150	140
3	F50, 15-17	HP	35	11	150	73
4	WB, 38-39	MSA1	15	7	140	50
5	WB, 38-39	MSA1	143	16	200	80

*Sample volume and fragments were adjusted to achieve Density Analysis

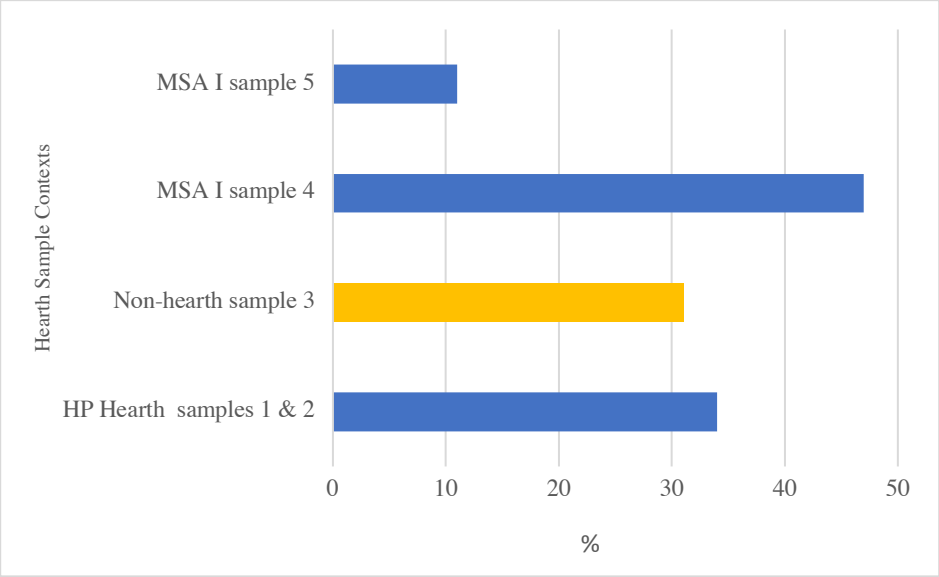


Figure 7.34: Klasies River Sample Density Analyses. Yellow bar = off-hearth sample. (Image: C. Larbey)

There are three points to be made from the density analyses in Figure 7.34: First, it is preferable that the samples be taken from the sides and middle of the hearth and, if possible, taken from the substrate separately. The substrates in the samples from Klasies River belong to a debris-covered, occupation layer on which the hearth was set and, therefore, were a separate archaeological context not associated with the hearth. Second, sample 4 came from just above bedrock, where Butzer describes sea incursion of the cave so this low density may be an issue of preservation (Butzer, 1982). Third, the densities of plant fragments do not vary dramatically between hearths.

7.2.5 Summary of Klasies River Results

Micromorphology research identified only three undisturbed hearths from which to take samples at Klasies River main site. These hearths proved to be unusual in that they represent multiple burning events in the same hearth, some probably within days of each other and some may be within the same season. Further micromorphology sampling and analysis have been conducted since the fieldwork for this research, the outcome of which suggests that single-use hearths may be more common than previously thought. These hearths are invisible to the naked eye. Ash hearths have been found in other Palaeolithic sites, where the contents have also burned to completion but their contents have not been analysed in this

way. Parenchyma fragments were also identified in the thin sections from two of the hearths (Sample 1 in the Howiesons Poort phase and Sample 5 in the MSA I phase).

The vertebrate, lithic and shell remains are either unburned or the upper sides are heated and come from the debris lying on the occupation layer on which the hearth was built. The ash layers also contain evidence of multiple burning events, being separated by thin, well-organised, re-crystallised ash surfaces indicating short intervals (days) between burnings. There was no indication of hollowing out, or of cleaning ashes, so there is no lenticular shaping to the three hearths sampled. The vertebrate remains from the Klasies River hearths are small: not necessarily from small fauna, but small pieces of bone. Some of the vertebrate remains show no evidence of burning. The lithic remains came only from the Howiesons Poort phase and are consistent with the techno-complexes manufactured and used during that period.

The botanical results indicate parenchyma in all samples, with repeated evidence of rhizome fragments. There is evidence of taproots, rhizomes, stem tubers and root tubers, many from monocot species, that would have been abundant in the vegetation around Klasies River throughout the MSA. Semi-aquatic plant species are also present in the assemblage. As was discussed in Chapter 3, prehistoric exploitation of semi-aquatic sedge and reed tubers and rhizomes is common and it is possible that these fragments could have come from water sources around Klasies River. The final highly fibrous fragment 136, sample 5 (Figure 7.34), may provide evidence of non-food plant use.

It is inferred from this evidence that the hunter-gatherers at Klasies River, both during the MSA I and Howiesons Poort phases, exploited the mosaic of biomes available around Klasies River. The vegetation in these biomes probably varied in proportions with oscillating climate change.

7.3 Blombos Cave

7.3.1 Blombos Cave Geoarchaeological Results

The micromorphology sampling was conducted in the same field season as the botanical samples were taken at Blombos Cave. However, as explained in Chapter 6, these were not taken in the same hearths and only occasionally in the same levels. The micromorphology analysis of some of the features in the southern section is not conclusive and research is ongoing. In particular, the nature of the grey layer that runs across the whole of the southern section profile (in red brackets in Figure 7.35), remains ambiguous. Samples were taken from CGAB h1 along the top edge of this grey layer and three samples were taken, one from each of three hearths running through and at the base of CGAC but in different quadrants.

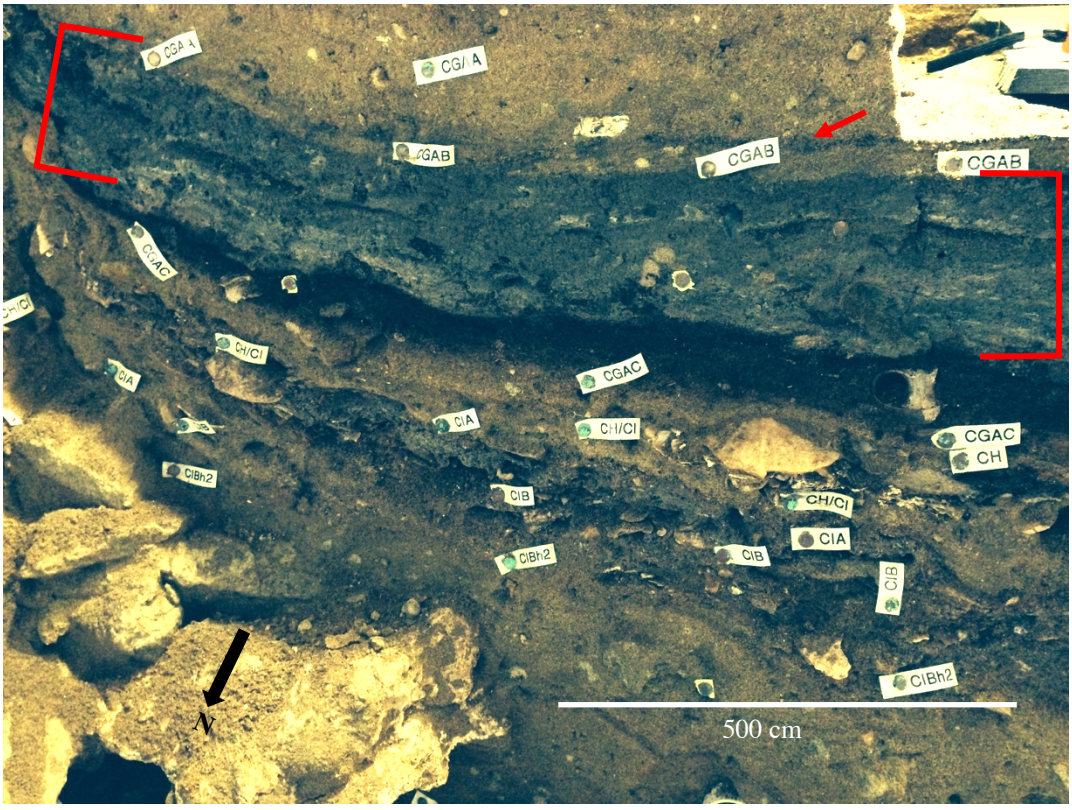


Figure 7.35: Grey layer (in red brackets) runs through southern section above CGAC, finishing with CGABh1. Image: C. Larbey).

The hearth features were identified visually in section through their concave shape, carbonised layer and occasionally ashy layers. There is no detailed micro-contextual analysis.

7.3.2 Botanical Results from Blombos Cave

The total samples collected are detailed in Table 7.8

Table 7.8: Summary of Botanical Samples Data from Blombos Cave, South Africa

	Quadrant	Unit	Piece Plot	Volume (ml) max.	Weight (g)	OSL Date (kya)	Phase	Comments
1	G7a	CD	2360	500	0	75	Still Bay	Floated in field, not possible to weigh
2	G7a	CD	2360	250	0	75	Still Bay	
3	H7a	CGAC	-	500		85	MSA II	
4	I6c	CF	2406	500	406.39	77	Still Bay	Sandy not hearth-like
5	G7a	CFB/CFC	2695	400	436.52	70	Still Bay	Dense layer
6	G7b	CGABh1	2688	650	512.73	81	MSA II	Putative hearth
7	I6c	CGAC	-	250	96.09	85	MSA II	Putative hearth
8	G7b	CGAC	2728	2000	805.55	85	MSA II	Very lumpy matrix, with loose sterile layer on top of thin charred level. Maybe one or two use hearth. 50% screened
9	H7a	CGAC	2728	500	456.36	85	MSA II	Black layer under G7b-CGAC hearth 50% screened
10	F7b	CFA	-	125	40	70	Still Bay	Fatty** ash layer, small off-hearth sample from standard soil sample

* Volumes of samples 1-3 were taken in the field using a measuring jug and are, therefore, approximate.** 'Fatty' describes a grey, greasy feeling layer, that is not a hearth context but appears to contain ash. This layer was described by the excavator C. Henshilwood.

Samples 1-6 were taken during excavation at Blombos Cave and were block, untrowelled samples removed from darkened areas identified as hearths during the process of digging. Samples 7, 8 and 9 were taken as block samples from the south face of the section at the same time as micromorphology samples were being

taken. Sample 10 was an off-hearth sediment sample taken for comparison. It is the protocol of the Blombos project to take a sediment sample from each layer and quadrant in case it is required for future research. Hence sample 10 has no piece plot number. Samples 1-3 were used for the flotation experiment detailed in Chapter 5. All the Blombos samples represent Class B samples as none could be confirmed as coming from intact hearths. The only two samples that indicated they were clearly hearth, from the general content of charcoal, burned bone and charred plant remains, were 6 and 8. The other samples appear to come from highly mixed hearths possibly caused by trampling. The results below represent the analysis of samples 4-10.

This excavation was conducted without the benefit of simultaneous micromorphology results and the evidence from some samples does not independently support a hearth context but suggests that sample 4 (I6c,CF) and sample 5 (G7a, CFB/CFC) may have come from an occupational debris layer. Blombos Cave poses taphonomic challenges because the small size of the cave means that it is almost inevitable that hearths will not have remained undisturbed and will have been trampled. However, evolving research techniques, such as the use of glauconite to identify hearth contexts, will be invaluable (Haaland *et al*., 2017). Hearth contexts were also more easily identified in section than during excavation.

A feature of the Blombos samples is that conservation is generally poor, with an increased frequency of mechanically crushed plant tissue, compared with Klasies River, possibly as a result of trampling or raking out. The botanical samples from the Blombos Cave samples included disrupted parenchyma, which was not seen at Klasies River and, for the first time, and in only one context, the occurrence of charred legumes.

Sample 4

From Quadrant I6c, Level CF, Southern Section in the Still Bay Phase (77-79 kya)

Sample 4 was taken during excavation and came from a darkened layer in the sediment that was interpreted as a hearth. Once dried, the sediment was very sandy and friable and the results from this level do not support the identification of this context as a hearth. Sample 4 may have come from an occupation level and the results detailed below may derive the debris from that level.

Botanical results from Sample 4

Table 7.9: Botanical results from Sample 4, I6c CF, Southern Section, Still Bay Phase, Blombos Cave

No. Fragments	Category
9	Parenchyma & disrupted parenchyma
12	Fused parenchyma
3	Crystals (rhomboid & raphide)
1	Secondary root xylem
10	Wood
4	Mixed matrix
2	Bone
4	Sediment
23	Unid plant tissue
68	Total

Fragment 68, Sample 4 – Parenchyma and Fused Parenchyma

There is fused parenchyma in around 20% of the assemblage, of which fragment 68 is an example (Figure 7.36)

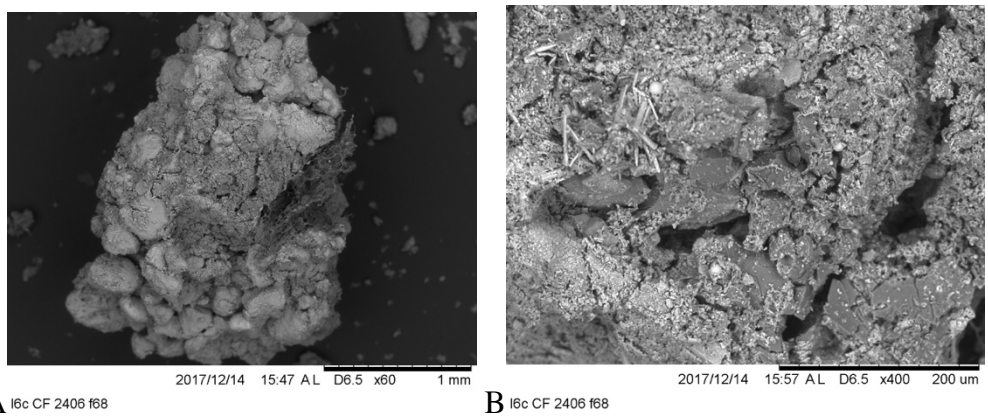


Figure 7.36: Fragment 68, sample 4, Blombos Cave: fused parenchyma and raphide crystals. A: fragment 68 whole image; B: fused parenchyma and raphide crystals. (Micrographs: C. Larbey)

Fragment 68 also had unusually preserved parenchyma in three dimensions (Figure 7.37).

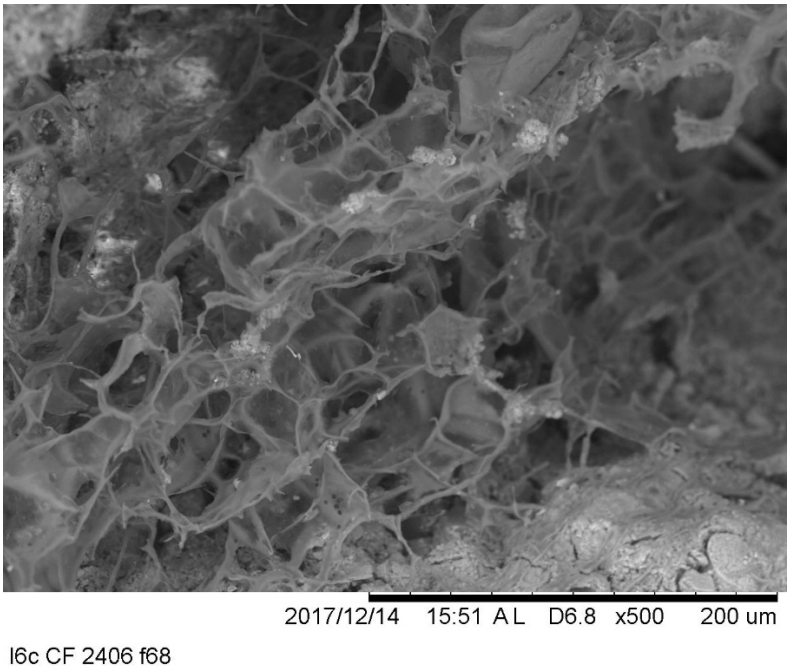


Figure 7.37: Fragment 68, sample 4, Blombos Cave: parenchyma with lumina visible. (Micrograph: C. Larbey).

The delicate cell structure preserved in Figure 7.37 can be seen in samples from the Klasies River modern reference collection at Figure 7.38.

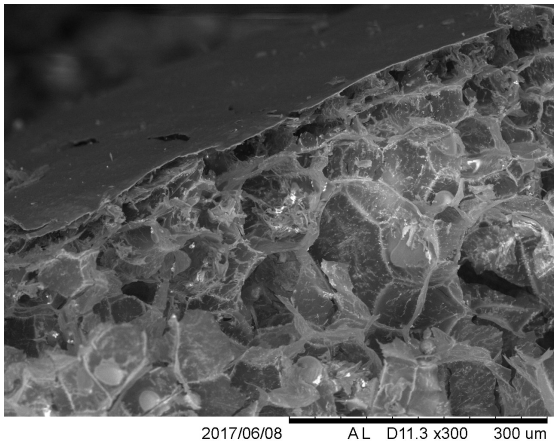


Figure 7.38: The delicate parenchyma cells of dried and charred *Haemanthus albifloss* bulb from the Klasies River modern parenchyma reference collection. (Micrograph: C. Larbey)

Fragment 36, Sample 4 – Rhomboid Crystals

Clues as to the presence of starch or parenchyma often came from calcium oxalate crystals that appear to be able to better withstand the mechanical stress of this layer than the parenchyma itself. Fragment 36 exhibits calcium oxalate rhomboid crystals and some fused parenchyma in an otherwise 'messy' fragment (Figure 7.39).

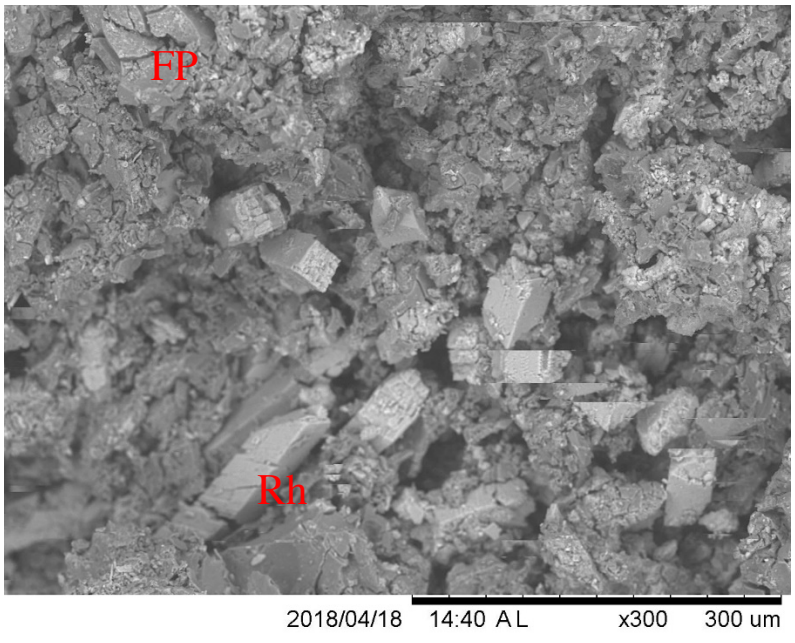


Figure 7.39: Fragment 36, sample 4, Blombos Cave: exhibits fused parenchyma (FP) and rhomboid crystals (Rh). (Micrograph: C. Larbey)

Sample 5

From Quadrant G7a, Level CFB/CFC, Southern Section in the Still Bay Phase (69-75 kya)

Sample 5 also appears to come from a debris layer, rather than a hearth context. There are few vertebrate remains and few botanical remains.

There were 77 unburned marine mollusc fragments in this sample, which attest to the continued used of marine resources during this cold period and suggest the close proximity of the coastline.

Botanical Results from Sample 5

Table 7.10: Botanical results from Sample 5, CFB/CFC, Southern Section, Still Bay Phase, Blombos Cave

No. Fragments	Category
23	Unid plant tissue
1	Wood
24	Total

Fragment 6 of the botanical remains provides a good example of broken plant tissue, possibly by trampling. This plant tissue appears to be mostly broken xylem, with no parenchymous tissue (Figure 7.40).

Figure 7.40: Fragment 6, sample 5, Blombos Cave: an example of broken plant tissue. (Micrograph: C. Larbey).

Sample 6

From Quadrant G7b, Level CGAB h1, Southern Section, MSA II Phase, c. 81 kya

This level has all the indications of a hearth and was taken from a charred section within the thick grey layer across the southern section.

Botanical Results from Sample 6

Table 7.11: Botanical results from Sample 6, G7b, CGAB h1, Southern Section, MSA II phase, Blombos Cave

No. Fragments	Category
11	Parenchyma
20	Disrupted parenchyma
1	Fused parenchyma
2	Fungi
10	Mixed matrix
44	Unid plant tissue
88	Total

Sample 6 has provided some of the most significant botanical results from Blombos Cave.

Fragment 1 is a rare example of well-preserved, rounded, tuber parenchyma. There are no other characteristics visible but the continuous and rounded nature of this fragment may indicate that it comes from a highly parenchymous tuber (Figure 7.41).

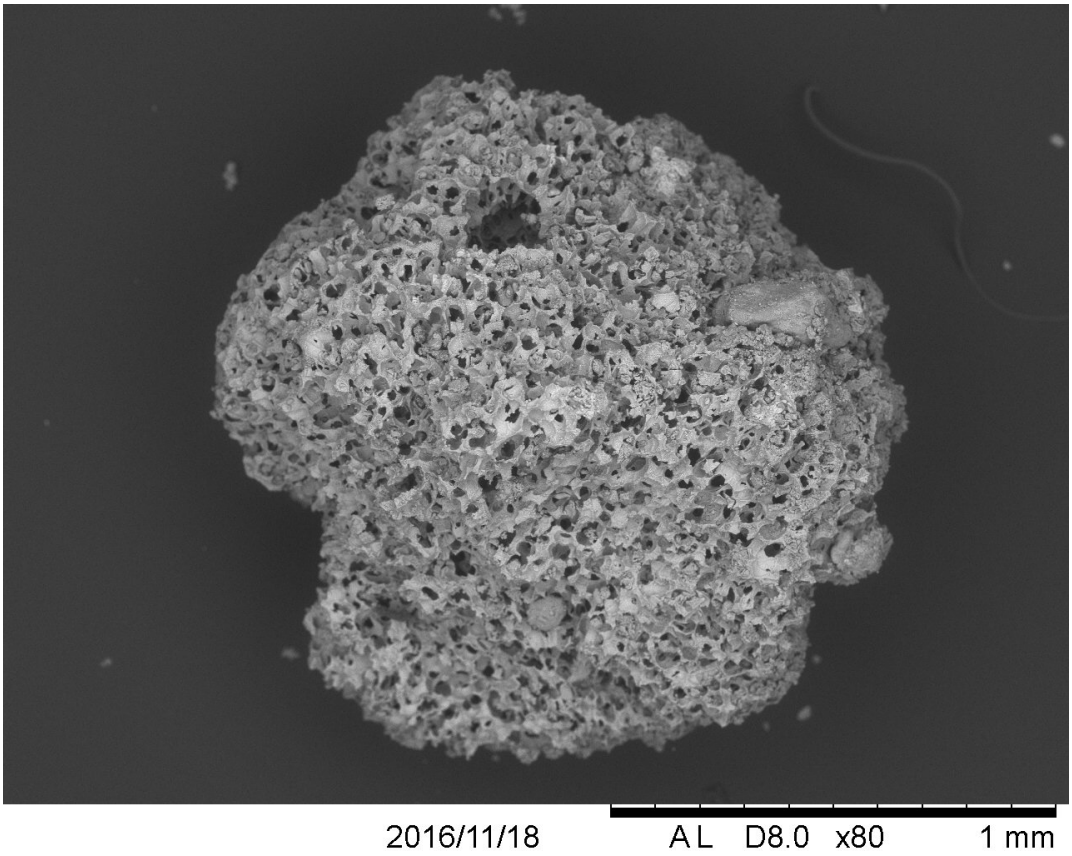
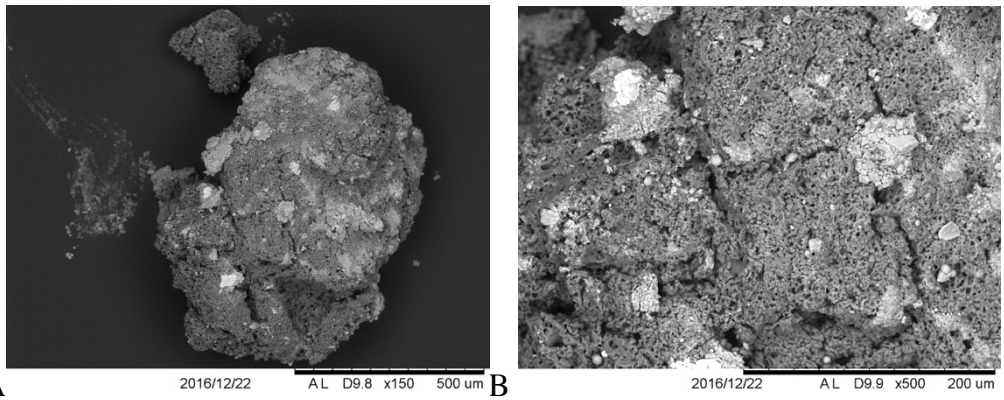


Figure 7.41: Fragment 1, sample 6, Blombos Cave: is an example of tuber parenchyma with no characteristics visible other than parenchyma cells. (Micrograph: C. Larbey)

Sample 6 also contained fragments of well-conserved rhizome parenchyma (Figures 7.42, 7.43, and 7.44).



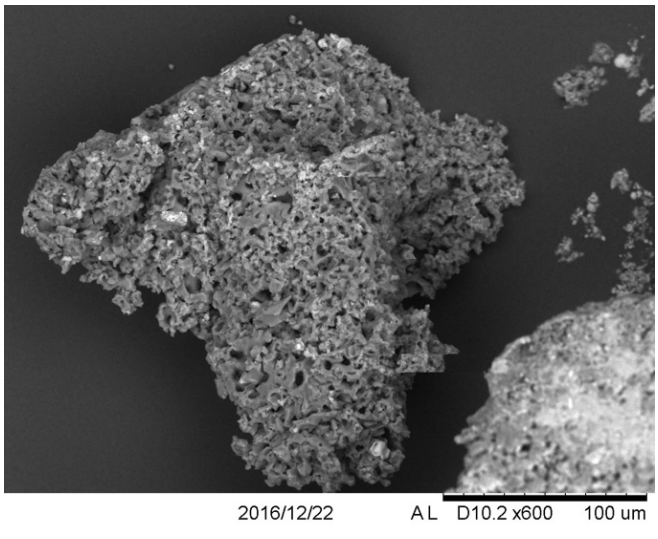


Figure 7.42: Fragment 64, sample 6, Blombos Cave: rhizome parenchyma. A: whole image; B: rhizome pith parenchyma; C: close-up of rhizome pith parenchyma. (Micrographs: C. Larbey).

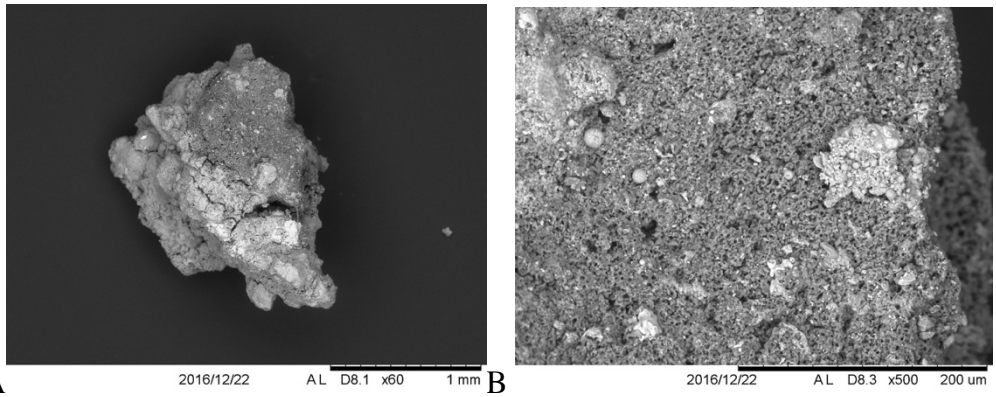


Figure 7.43: Fragment 81, sample 6, Blombos Cave: rhizome parenchyma. A: whole image; B: rhizome pith parenchyma. (Micrographs: C. Larbey).

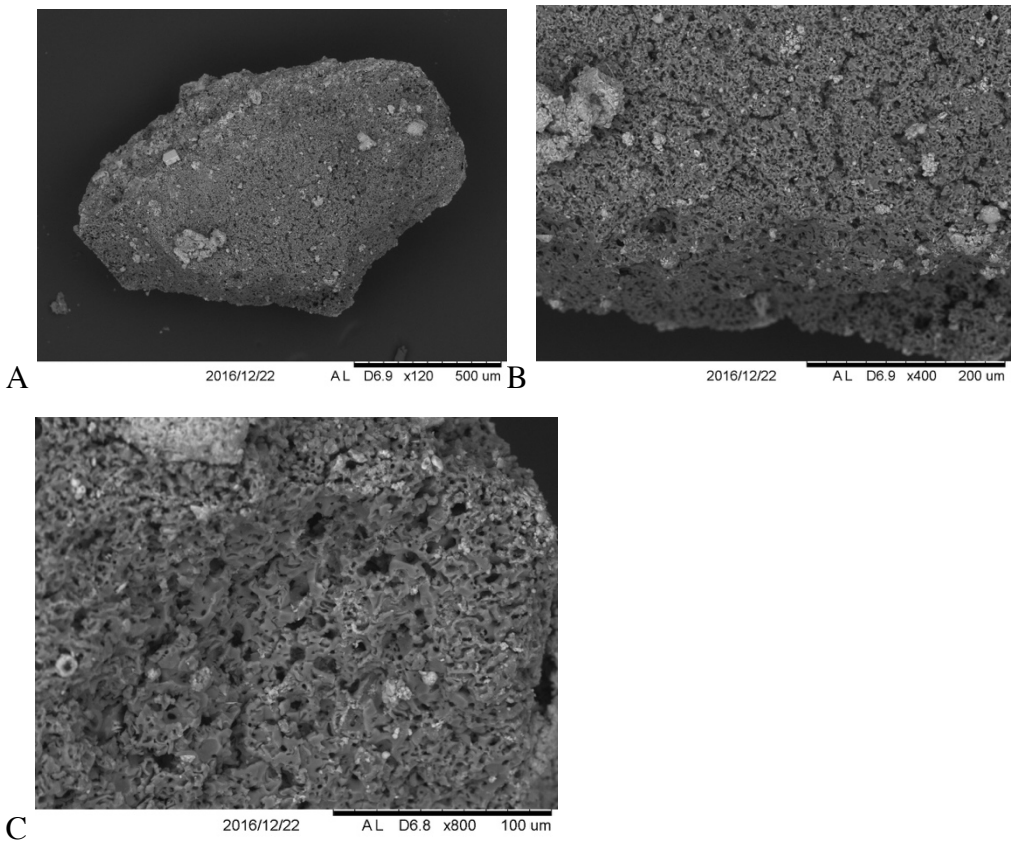


Figure 7.44: Fragment 85, sample 6, Blombos Cave: rhizome pith parenchyma: A: whole image; B: Rhizome pith parenchyma; C: close-up of deformed cell structure of rhizome pith parenchyma. (Micrographs: C. Larbey)

The images in this section define the parenchyma category, including the well-conserved tuber parenchyma and three separate fragments of rhizome parenchyma. The latter is identified by the pith parenchyma in Figures 7.43C, 7.44B and 7.45C, all of which exhibit a vesicular matrix that has been deformed by escaping moisture when heated. Disrupted parenchyma of a different sort, therefore, was distinctive.

Fragments 101 and 130 – Disrupted Parenchyma and Processing

Poorly preserved and mechanically stressed or 'broken' fragments are common to both Blombos Cave and Klasies River. The following fragments stood out as different and were researched further. Figure 7.45 represents the results of the experimental processing of tubers from *Bolboschoenus maritimus* (L.) Palla (sea club-rush) by Wollstonecroft *et al*. (2008). The remains of sea club rush have been frequently recovered from Epi-Palaeolithic sites across the Near East. The results

of this experiment showed that pulverising was a necessary step not only to make these tubers edible but to make the starch accessible for humans. Heating alone did not soften the tuber, it only gelatinised the starch granules (Wollstonecroft *et al*., 2008).

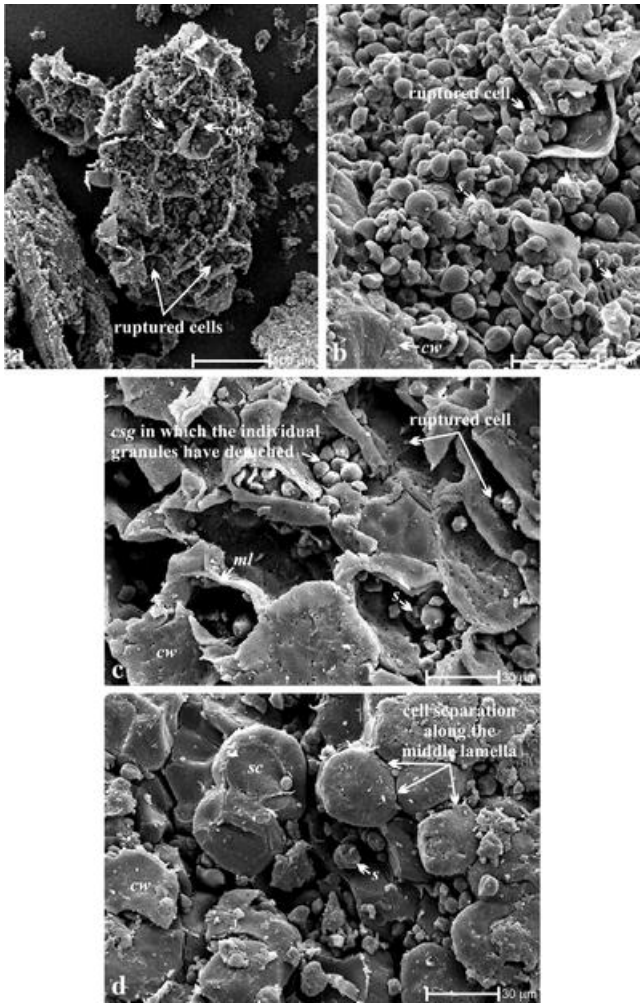


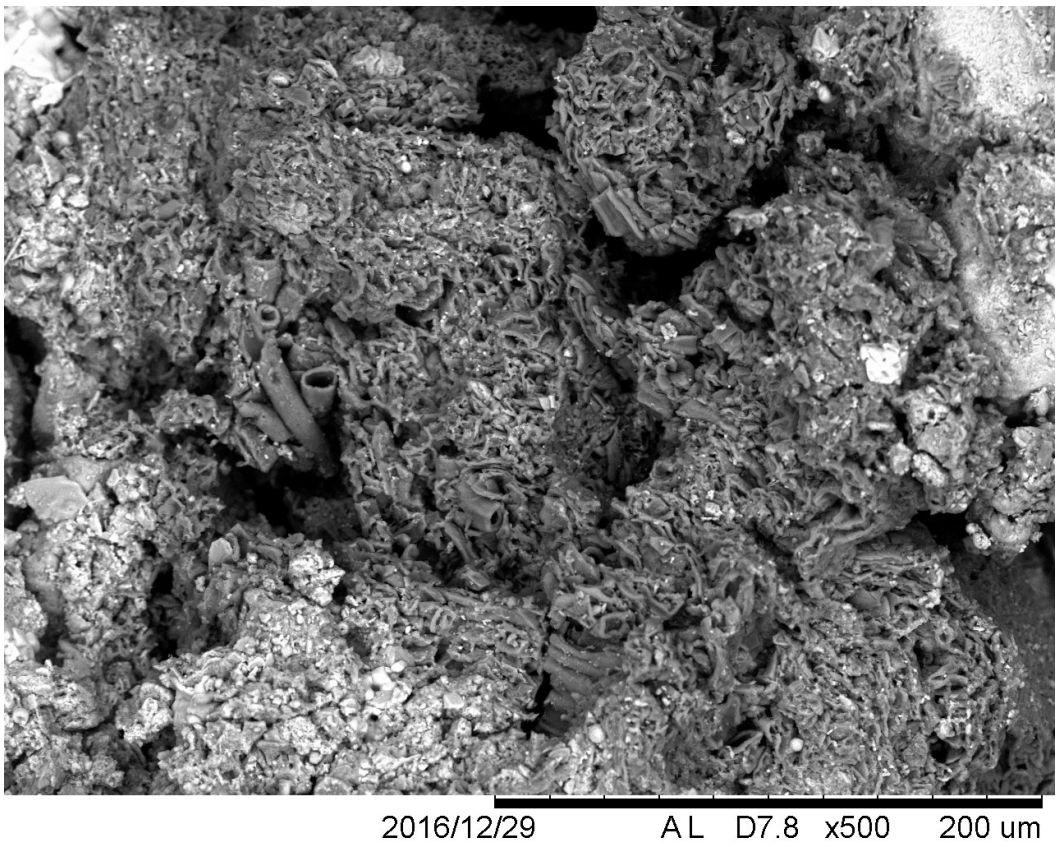
Figure 7.45: "Pulverised SCR parenchyma tissue, shown with SEM: cell rupture is evident in a–c and cell separation and fissures along the middle lamellae are visible in d. csg = Compound native starch granule, cw = cell wall, ml = middle lamella, s = single native starch granule, sc = separated cell, v = vascular tissue" (Wollstoncroft *et al*. 2008: S24, Figure 4).

Figure 7.45c in particular provides a useful comparison with the archaeological remains recovered from Sample 6. There is only one fragment that may contain starch granules in the archaeological samples and so in most fragments it is no longer possible to see any separation of cells along the middle lamella, but there may be some useful observations to be made.

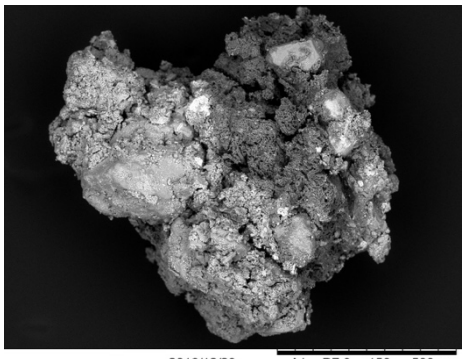
Fragment 101, Sample 6

Fragment 101 in Figure 7.46A exhibits a similar ruptured cell pattern to that in Figure 7.46c. Most notably, the pulverised cell walls have a folded-in or collapsed-in appearance that would be unlikely to occur prior to heating. After heating the cell walls break into fragments. The matrix in 7.46A appears to have been pulverised prior to heating.

A



B



C

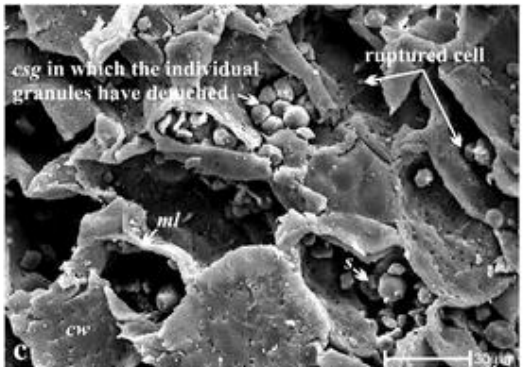


Figure 7.46: Pulverised cell structure comparison with Blombos Cave material. A: the cell structure in fragment 101 exhibits similar rupture patterns to that in C; B: whole image of fragment 101; C: micrograph of pulverised sea club rush tuber from Wollstoncroft *et al*. (2008: S24, Figure 4). (Micrographs A & B: C. Larbey).

By contrast, Figure 7.47 shows fragments 138 and 121 from the same sample, exhibit poorly preserved and broken parenchyma. Poorly preserved parenchyma is identified when the cells are not distinct because of a general degrading of tissue, but were clearly once parenchyma cells. Parenchyma fractured through mechanical

stress often displays sharp edges and is fractured through a number of cells that have been fused together by heat.

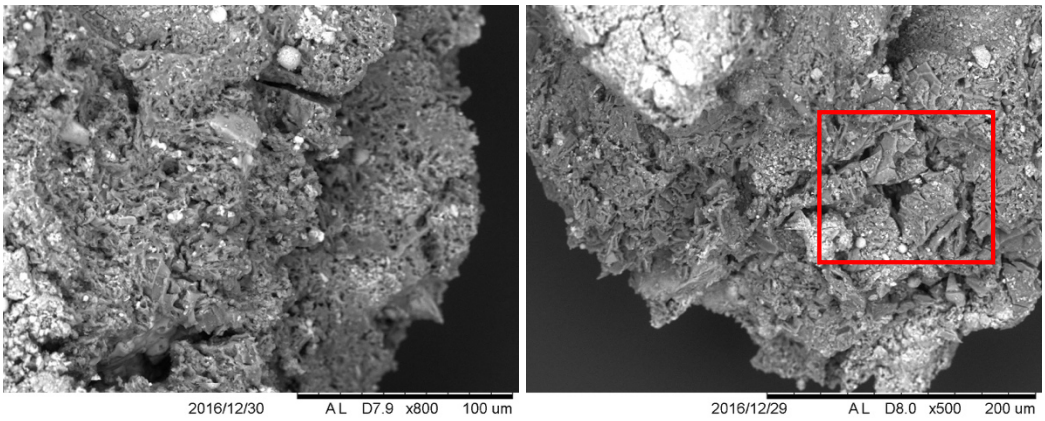


Figure 7.47: Poorly preserved and broken parenchyma, sample 6, Blombos Cave. Left: fragment 138 exhibits poorly preserved parenchyma; right: fragment 121 shows broken parenchyma where the fragments are fused and broken edges are angular in red box. (Micrographs: C. Larbey)

It is possible that parenchyma that has been pulverised and heated may subsequently suffer breakage through mechanical fracture, such as trampling. However, these fragments represent those that appear to show similarity with the pulverised cell wall folded/collapsed in appearance. The cell structure is often either deformed from just heating, as in rhizome pith parenchyma, or the formation of vesicles (air pockets) can compress the tissue against the epidermis (Hather, 1993).

Fragment 130 also exhibits the same fractured but folded cell structure of the pulverised tubers. Disrupted fragments and their associated matrix often include seed testa and these are the only contexts in which seed testa appear (Figure 7.48). This fragment appears to be a sample of mixed cooked foods.

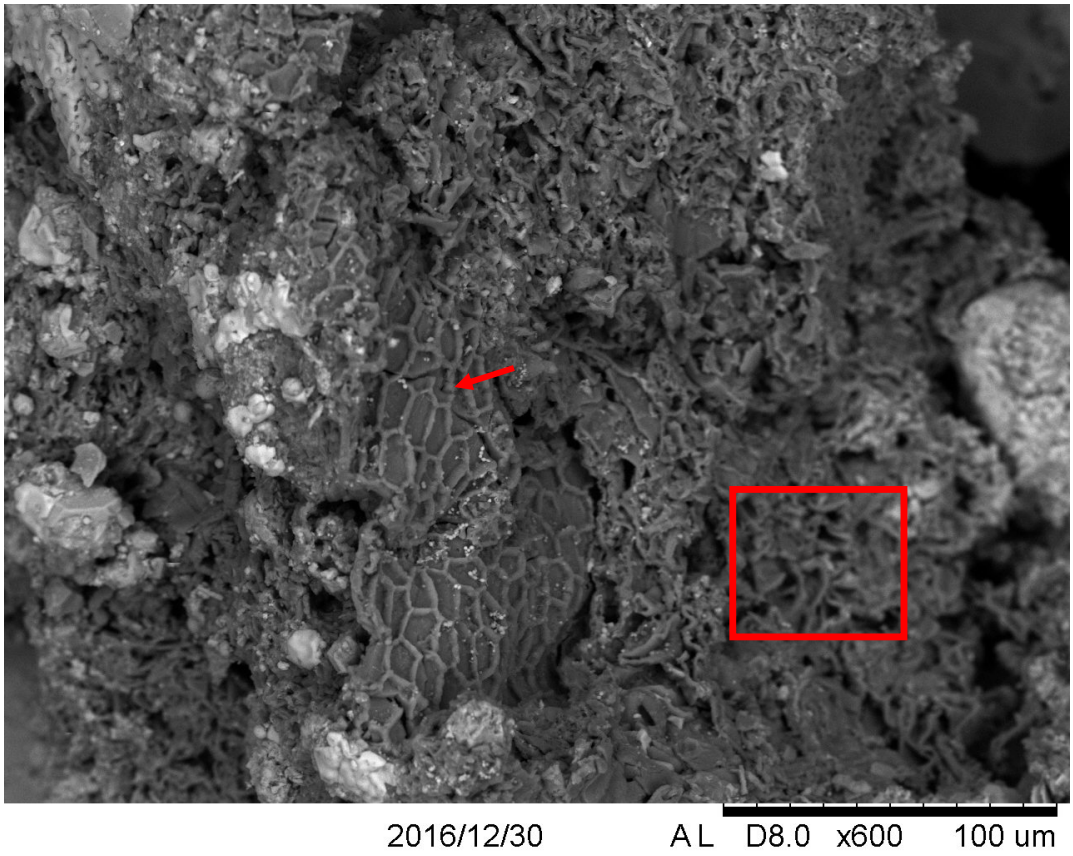


Figure 7.48: Fragment 130, sample 6, Blombos Cave: exhibits putative pulverised cell structure (red box indicates just one area) and ruptured seed testa, probably also pulverised, included in matrix (red arrow). (Micrograph: C. Larbey)

Disrupted Parenchyma from Sample 8

From Quadrant G7b, Level CGAC, Southern Section, MSA II Phase, c. 85 kya

Sample 7 is from a non-hearth context and for the sake of continuity, this section will proceed directly to the analysis of disrupted parenchyma fragments from Sample 8. Sample 7 will be then analysed subsequently.

Further disrupted parenchyma fragments have been recovered from Sample 8, context G7b CGAC, also a hearth from the grey layer that runs across the whole southern section. The disrupted parenchyma micrographs from that context are inserted here for the purpose of comparison (Figures 7.49, 7.50, 7.51, 7.52, 7.53, and 7.54).

Fragment 61, Sample 8, G7b CGAC – Disrupted Parenchyma

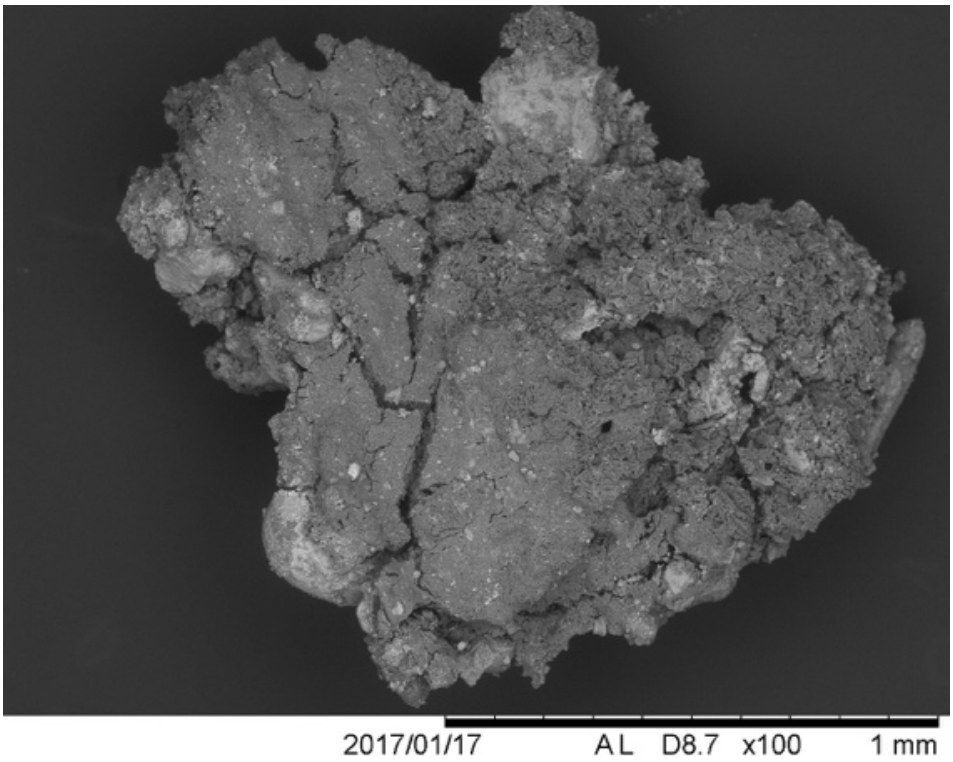


Figure 7.49: Fragment 130, sample 8, whole image. (Micrograph: C. Larbey).

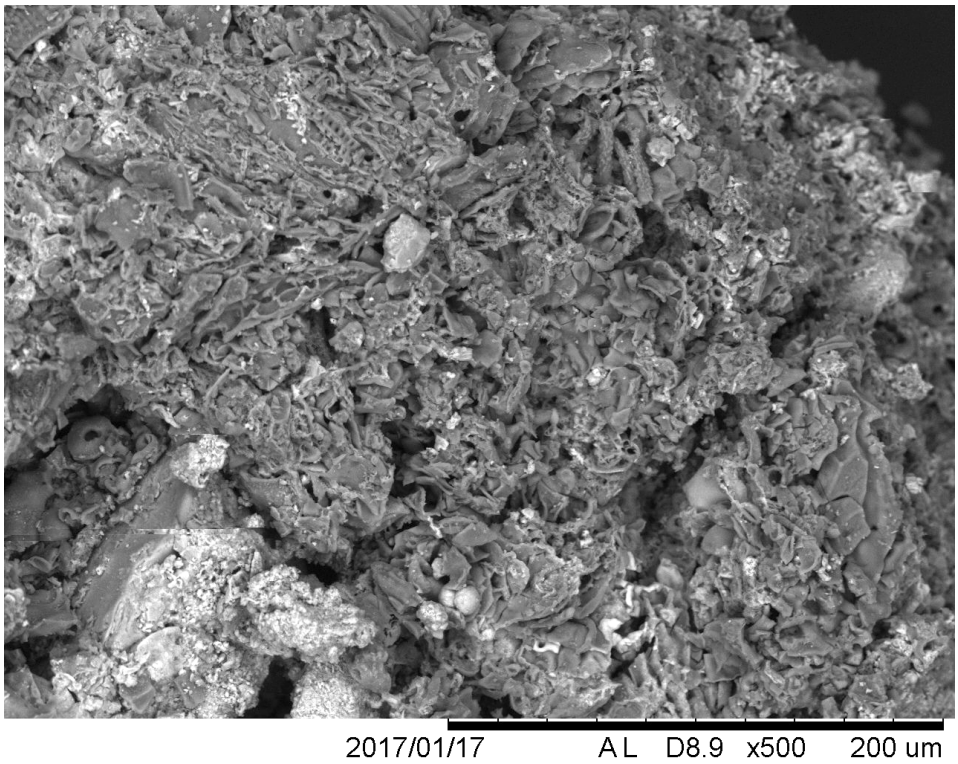


Figure 7.50: Fragment 61, sample 8, exhibits putative pulverised parenchyma. (Micrograph: C. Larbey).

Fragment 71, Sample 8, G7b CGAC - Disrupted Parenchyma

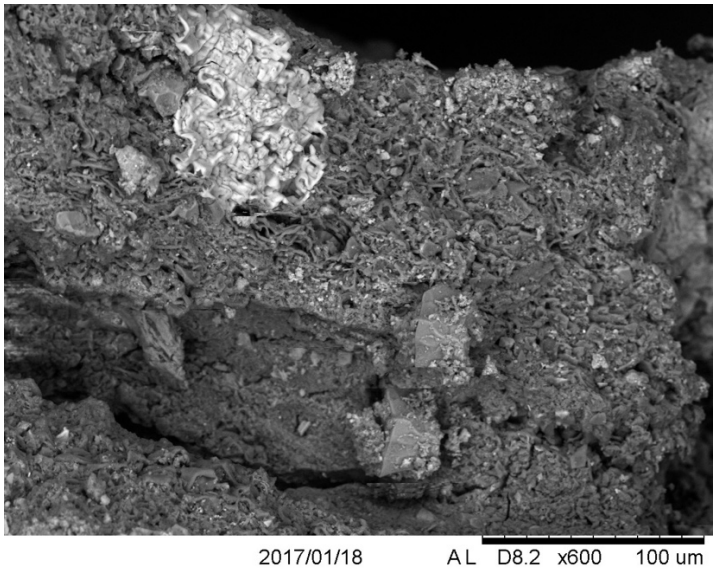


Figure 7.51: Fragment 71, sample 8 exhibits pulverised parenchyma. (Micrograph: C. Larbey).

Fragment 74, Sample 8, G7b CGAC – Disrupted Parenchyma

Fragment 74 is a good example of parenchyma cell folding, the result of pulverising prior to heating (Figure 7.52).

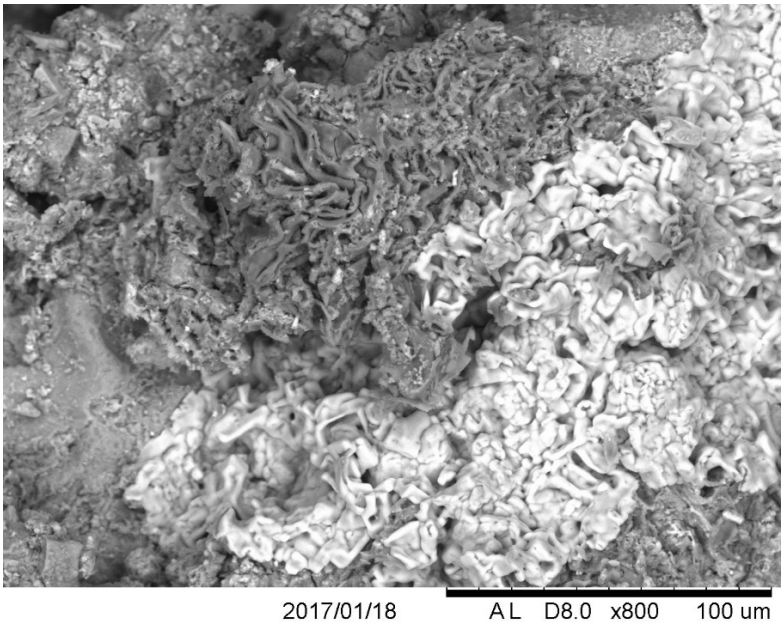


Figure 7.52: Fragment 74, sample 8, exhibits putative pulverised parenchyma. (Micrograph: C. Larbey).

Fragment 59, Sample 8, G7b CGAC – Disrupted Parenchyma

Although fragment 59 exhibits putative pulverised cells, the matrix itself appears to be fused and then fractured (Figure 7.53). The breakage is possibly mechanical fracture rather than from heat.

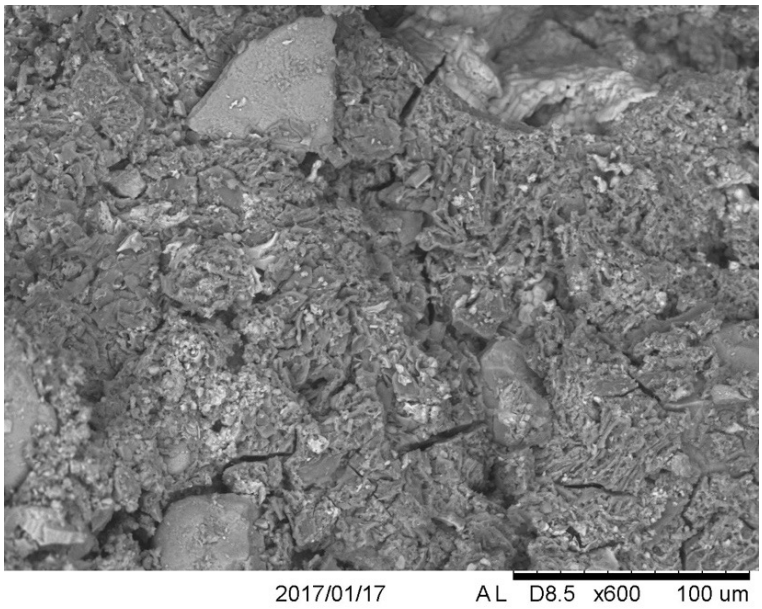


Figure 7.53: Fragment 59, sample 8, putative pulverised parenchyma in fused matrix. (Micrograph: C. Larbey).

Fragment 108, Sample 8, G7b CGAC – Disrupted Parenchyma

Fragment 108 also exhibits putative pulverised cells amongst a mechanically fractured matrix (Figure 7.54).

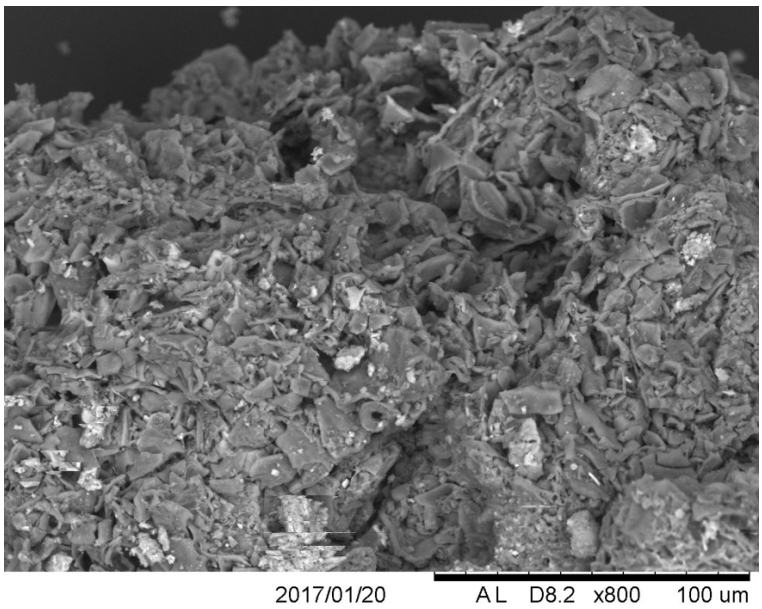


Figure 7.54: Fragment 108, sample 8, putative pulverised parenchyma in a mechanically fractured matrix. (Micrograph: C. Larbey)

Fragment 102 is the only specimen in the assemblage that appears to have intact parenchyma cells. None of the clusters of intact parenchyma exhibit any cell separation along the middle lamella of the cells here. Heating does not appear to have broken down the cells (Figure 7.55). However, given the stomate (circled), it is possible that this parenchyma comes from the mesophyll layer in leaves (Campbell *et al*., 2011).

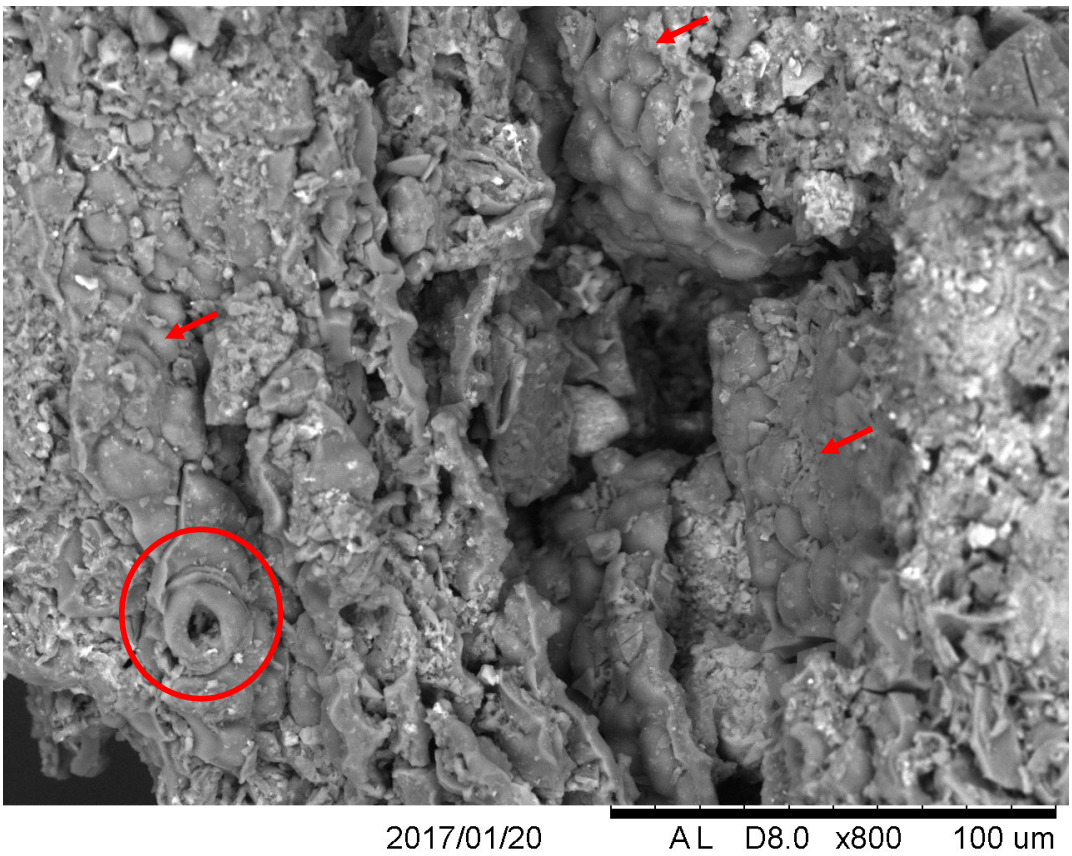


Figure 7.55: Fragment 102, sample 8, exhibits three clusters of intact parenchyma cells, without any cell separation along the middle lamella, possibly the spongy mesophyll layer of leaves, MSA II phase, Blombos Cave. The arrows point to intact parenchyma cells and the red circle encloses the stomate. (Micrograph: C. Larbey).

The hypothesis offered from the evidence in this section is that hunter-gatherers at Blombos Cave were pulverising certain geophytes to improve their digestibility or nutritional value prior to heating.

The Balance of Sample 8

From Quadrant G7b, Level CGAC, Southern Section, MSA II Phase, c. 85 kya

This block sample was cut from a hearth context in the southern section and comes from the base of the thick grey lens that crosses the whole of the southern section.

This block botanical sample had a very loose, friable layer on top from which fragments 1-53 were recovered. The balance of Sample 8 contained a charred layer with a large, solid ash block from which fragments 54-108 were recovered. Given the size of the sample, only 50% of the sample was analysed. The block sample was divided by weight, rather than divided by volume using a riffle box, in order to preserve the stratigraphic integrity of the block. There appeared to be no difference in either half and the 50% chosen for analysis was chosen randomly (with the help of colleague).

The top layer was composed of loose friable sediment, which was dominated by small clusters of burned sediment, small fragments of bone of >1mm and plant tissue which could not be identified due to very poor preservation. The majority of the fragments recovered come from the charred lens and ash block beneath.

Botanical Results from Sample 8

Table 7.12: Botanical results from Sample 8, G7b, CGAC, Southern Section, MSA II phase, Blombos Cave.

No. Fragments	Category
19	Disrupted parenchyma
9	Broken parenchyma
3	Fused parenchyma
3	Legumes
42	Unid plant tissue
76	Total

Disrupted parenchyma from this sample was covered in the section above along with sample 6 from G7b CGAB h1.

The other outstanding feature of this sample was the abundance of burned legumes in the ash layer. These remains were extremely fragile and liable to disintegrate upon handling so the attempt to extract and count all from this hard ash layer was abandoned and only three legumes were extracted from the sample and two analysed (Figure 7.56).

The identification of wild legumes of the Fabaceae family come from the hilum, which is pronounced in both samples and both have the appearance of two cotyledons. The outer testa also shows a textured pattern that is common to some legume species (Figure 7.56B) (Günes and Alí, 2011).

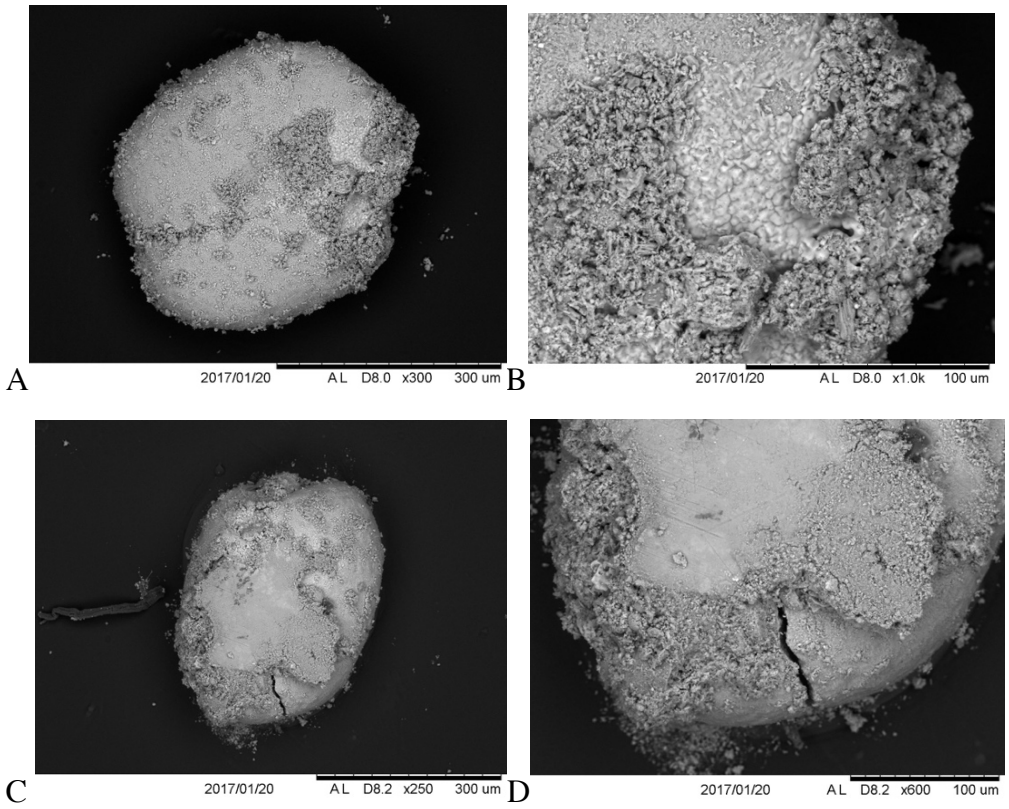


Figure 7.56: Legumes from sample 8. A: whole image of legume 1; B: partial legume textured testa; C: whole image of legume 2 showing clear hilum and dicotyledon shape; D: close-up image of legume 2 showing sediment covering. (Micrographs: C. Larbey)

Sample 7

From Quadrant I6c, Level CGAC, Southern Section, MSA II Phase, c. 85 kya

Sample 7 was a non-hearth sample taken for comparison in the MSA II phase. Fifty percent of this sample was analysed.

Botanical Results from Sample 7

Table 7.13: Botanical results from Sample 7, I6c, CGAC, Southern Section, MSA II phase, Blombos Cave.

No. Fragments	Category
6	Disrupted parenchyma
7	Unid plant tissue
1	Pollen/fungus
1	Dung with spherulites
15	Total

Fragment 7, Sample 7 – Disrupted Parenchyma

Similar disrupted parenchyma suggests to processing prior to heating (Figure 7.57).

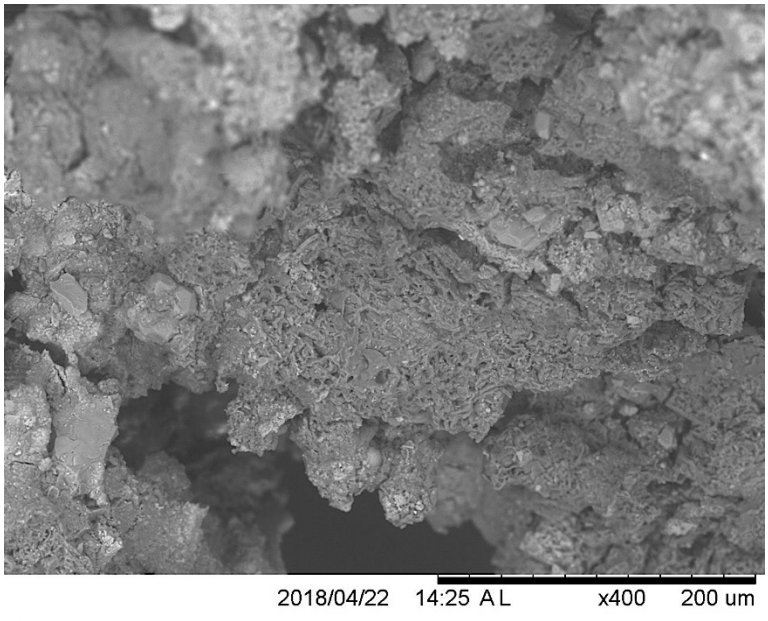


Figure 7.57: Fragment 7, sample 7, exhibits a small area of disrupted parenchyma. (Micrograph: C. Larbey)

Fragment 5, Sample 7 – Coprolite

Spherulites were abundant throughout the sample in Figure 7.58 and the 'crusted' nature of this fragment suggests an animal coprolite (Pesquero *et al*., 2014).

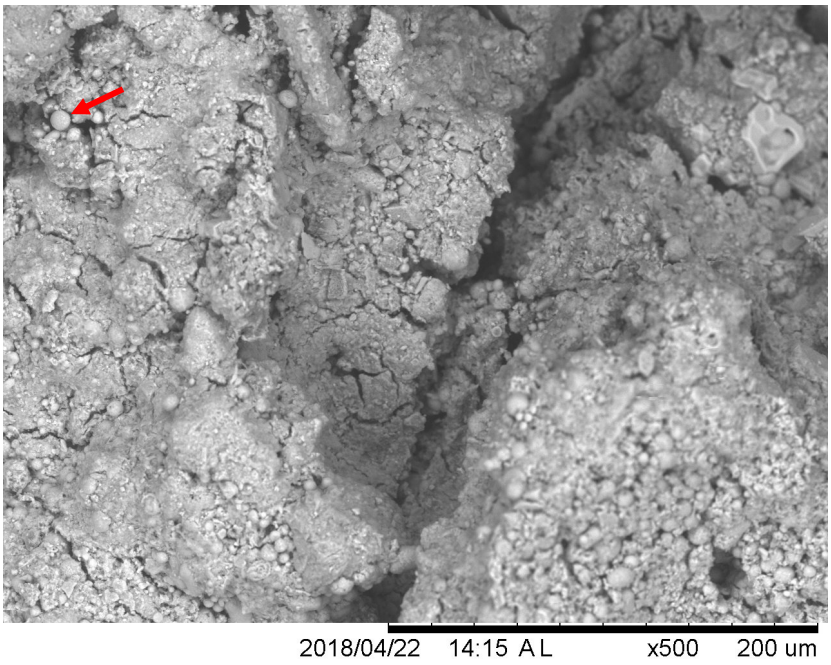


Figure 7.58: Fragment 5 contains spherulites (red arrows), which suggests animal coprolite. (Micrograph: C. Larbey)

Fragment 21, Sample 7 – Pollen grain/Fungus

Fragment 21 could either be a pollen that has preserved most of the exine or may be a fungal growth (Figure 7.59).

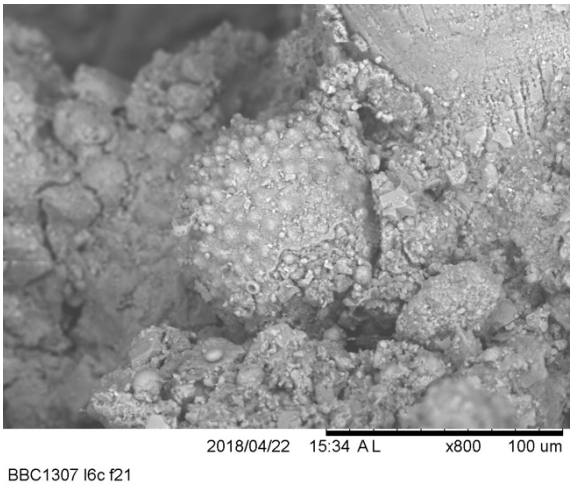


Figure 7.59: Fragment 7, sample 7, Blombos Cave: pollen grain with largely preserved exine (possibly fungus). (Image C. Larbey)

Sample 9
From Quadrant H7a, Level CGAC, Southern Section, MSA II Phase, c. 85 kya

The stratigraphy of this block (Figure 7.60) appeared to be a hearth in section but may not have been an undisturbed hearth.

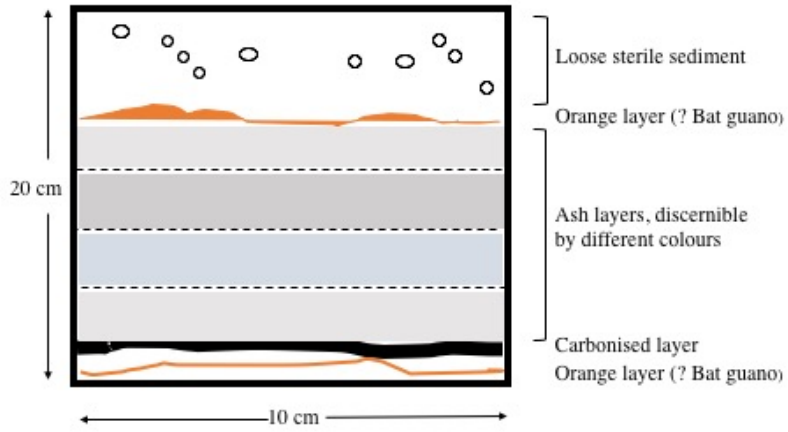


Figure 7.60: Stratigraphic layers within sample 9, H7a, CGAC. (Image: C. Larbey)

The loose sediment layer was sterile and the orange layer, frequently bat guano (Mentzer, 2015, Pers. Comm.), is often synonymous with human absence from the cave. The ash layers may have been separate burning events or may have been ash dumps but few plant remains were recovered from these layers. Black fragments were recovered from the carbonised layer but these appear to be blackened sandy clusters.

Botanical Results from Sample 9

Table 7.14: Botanical results from Sample 9, H7a, CGAC, Southern Section, MSA II phase, Blombos Cave.

No. Fragments	Category
7	Disrupted parenchyma
2	Broken parenchyma
2	Fungi
17	Unid plant tissue
28	Total

Fragment 13 is parenchymous tissue but difficult to discern. The following demonstrates the line of analysis taken in identification (Figure 7.61).
The overall assessment is that this is likely to be a poorly preserved, over-cooked fragment of rhizome parenchyma. Some parts of the fragment are better preserved than others and the separation of the fragment from the surrounding matrix is complex.

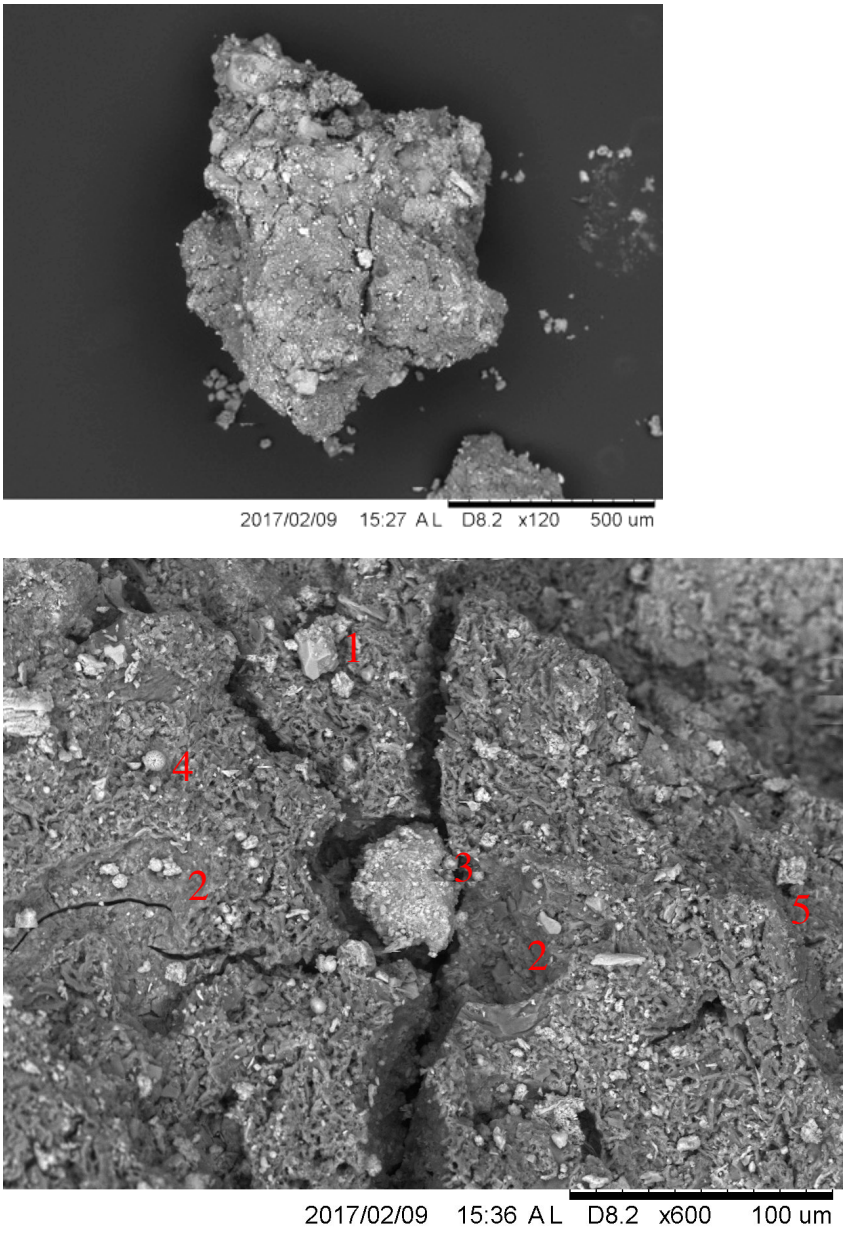


Figure 7.61: Fragment 13, sample 9, Blombos Cave: a borderline example. Above: whole image of fragment 13, sample 9 ; below: image of fragment with badly preserved parenchyma: 1 = wood crystal; 2 = possible relict secretory cavities of a rhizome; 3 = fragment of sediment fallen into relict secretory cavity; 4 = spherulite; 5 = fused parenchyma .(Micrographs: C. Larbey).

The crystal at 1 in Figure 7.61 is a calcium oxalate crystal of the type that commonly forms in the rays of wood and probably has come from the wood ash (Lens *et al*., 2008). The cavities at 2 (x2) appear to be secretory cavities that are common in rhizomes (Hather, 2000). The cavity in the centre appears to have epithelial cells, making this more likely to be a cavity than a dent in the fragment. The fragment at 3 is a piece of matrix sediment that appears to have fallen into the cavity. The sphere at 4 is one of several spherulites in this image and across the fragment. Composed of calcium carbonate, spherulites form in the guts of animals to aid digestion and are expelled in dung, which makes them a good indication of the presence of animal faecal matter. The dung can enter the cave during periods when humans were absent and animals use the cave for shelter. Hyaena coprolites are occasionally recovered in Blombos Cave, including during the author's fieldwork season. There were also a number of animal bio-galleries noted in section and it is also possible that burrowing animals such as rock hyrax could be responsible for dung in the matrix. Human faecal matter does not contain spherulites (Canti and Nicosia, 2018). The cracked and rather amorphous feature at 5 could be fractured wood, characteristic of the wood throughout the whole assemblage. However, the edges of this feature are rounded. It appears to be one piece which, in this context seems more likely to be fused parenchyma that has subsequently cracked due to heat stress.

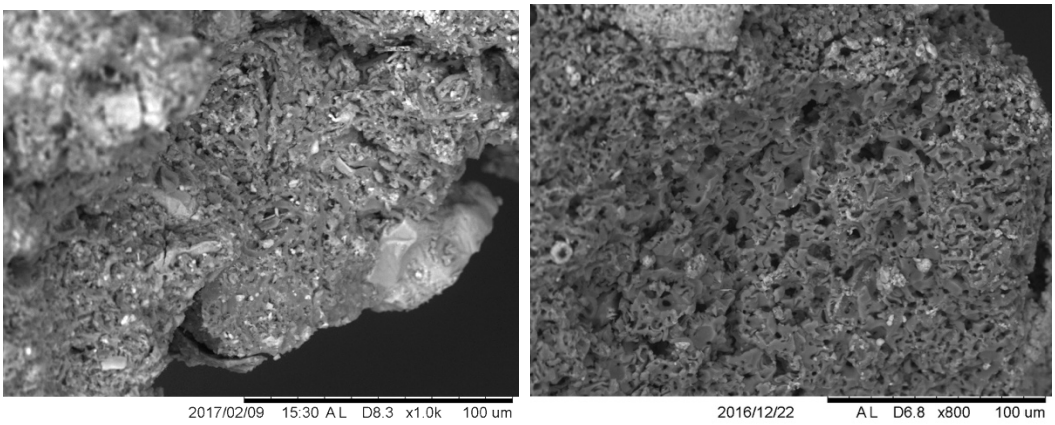


Figure 7.62: Fragment 13, sample 9, Blombos Cave: example of rhizome pith parenchyma. Left: fragment 13 exhibiting a more deformed version of the rhizome pith parenchyma, possibly as a result of higher levels of water, oil or sugar in the cells; right: rhizome pith parenchyma from fragment 85 in sample 6 for comparison. (Micrographs: C. Larbey).

Fragment 13 in Figure 7.62 shows a highly fused yet similar version to fragment 85. The level of water, oil or sugar in the plant prior to heating often determines the level of cell obliteration by the creation of a mass of small vesicles (air-holes). It is this process that creates the solid, sometimes vitreous appearance of fused parenchyma (Hather 2000: 32). In the case of fragment 13, it may be that there was a higher content of starch prior to burning, followed by mechanical stress in context that gave the fragment this appearance. The parenchyma does not appear to have been processed, despite the cell structure being deformed.

Fragment 62, Sample 9

Further confirmation of the presence of animal dung in the matrix comes from the abundance of micro-spherulites found as in fragment 62 (Figure 7.63).

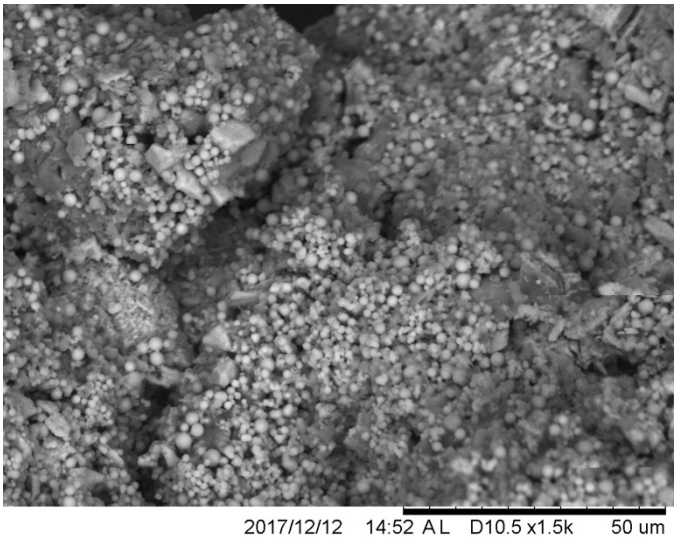


Figure 7.63: Micro-spherulites in Fragment 62, Sample 9, Blombos Cave. (Micrograph: C. Larbey)

Sample 10 – Off Hearth

From Quadrant F7b, Level CFA, Still Bay phase, 70 kya

Sample 10 was not a block sample taken by the author from a putative hearth context. It was a non-hearth sample, taken through the usual excavation protocol from troweled but unscreened sediment. The purpose of this sample was to act as a control for the method used during the excavation.

Botanical Results from Sample 10

Table 7.15: Botanical results from Sample 10, F7b CFA, Southern Section, Still Bay phase, Blombos Cave.

No. Fragments	Category
2	Parenchyma
1	Fused Starch
11	Wood charcoal
15	Unid plant material
29	Total

The conservation of cell structure was poor and often difficult to distinguish in this level. However, two fragments are worth noting:

Fragment 4, Sample 10 – Xylem Parenchyma

Despite the poor preservation of this fragment, it is possible to see elongated rectangular shaped parenchyma, with square ends but with no possibility to observe potential inter-cellular air holes because of the poor preservation. However, this is the first fragment to exhibit such parenchyma. The shape of parenchyma cells is influenced more by their location in the plant than by any characteristic of species (Hather, 2000) (Figure 7.64).

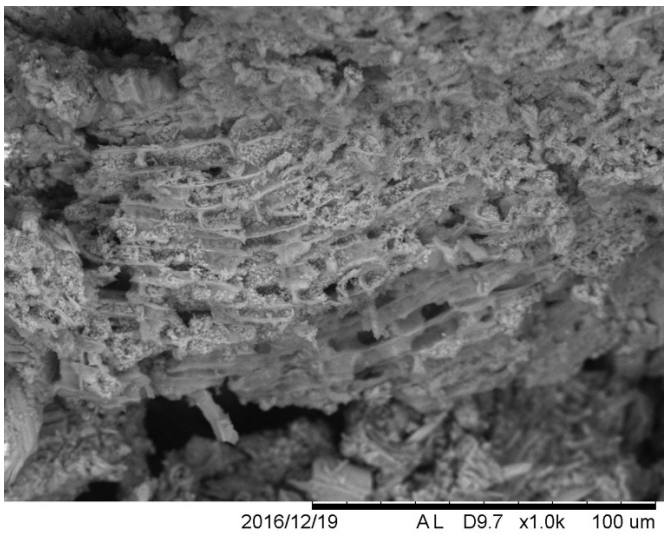


Figure 7.64: Fragment 4, sample 10, Blombos Cave: exhibits elongated parenchyma. (Micrograph: C. Larbey).

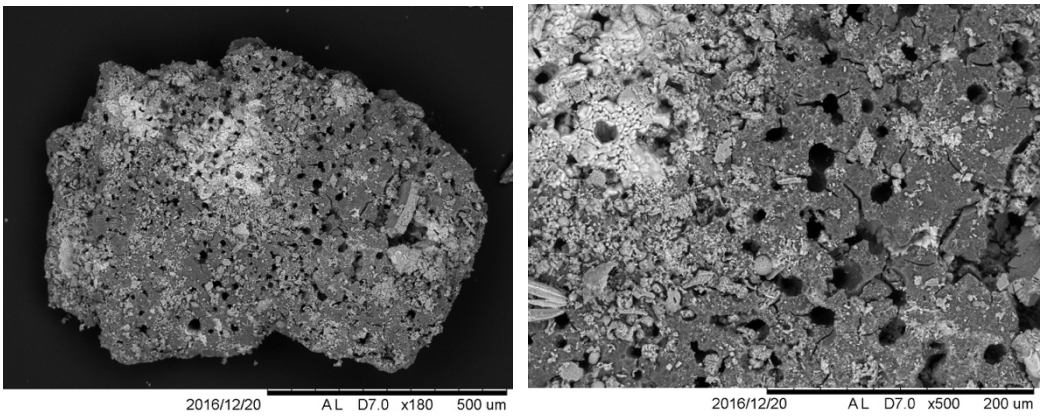


Figure 7.65: Fused parenchyma from fragment 38, sample 10, Blombos Cave. (Micrographs: C. Larbey)

Figure 7.65 shows a fragment of fused parenchyma, which, when added to the parenchyma in Figure 7.64, would indicate that the remains of cooked starchy plants appear in most contexts throughout Blombos Cave.

7.3.3 Blombos Cave Density Analysis

The Blombos Cave densities are consistent between phases and, although there are slightly higher densities at Klasies River, there is no dramatic variation between the different caves (Main Cave and Cave 1A) (Table 7.16 and Figure 7.66).

The off-hearth sample indicates the low densities of starch plants and there is one layer with no starch plant fragments at all. Given the low number of total plant fragments from this context, this difference may not be significant (Figure 7.65).

Table 7.16: Blombos Cave Results Data.

Sample No	Context	Phase	Total no. of plant fragments in sample	No. of starchy plant fragments in sample	Sample Volume (ml)	Density Analysis (no. of starchy plant fragments/litre sediment)
4	I6c CF	Still Bay	58	25	500	50
5	G7a CFB/CFC	Still Bay	24	0	400	0
6	G7b CGAB h1	MSA1	77	33	650	51
7	I6c CGAC	MSA1	14	6*	250	48
8	G7b CGAC	MSA1	76	31*	2000	31
9	H7a CGAC	MSA1	26	9*	500	36
10	F7b CFA	Still Bay	29	2	125	16

* = 50% of sample screened

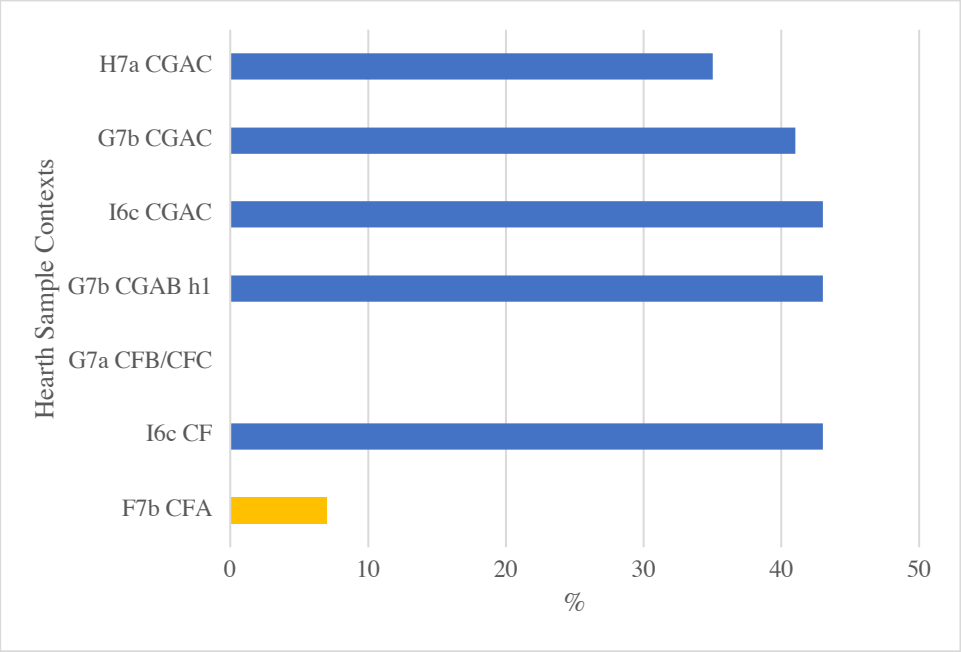


Figure 7.66: Blombos Samples Density Analyses. Yellow bar = off-hearth sample.

A further consistent feature in the Blombos numbers is the number of starchy plant remains as a percentage of the total plant remains (Table 7.17).

Table 7.17: Starchy plant fragments as a percentage of total plant remains, Blombos Cave.

Sample No	Context	Phase	Total No. of plant fragments in sample	No of starchy plant fragments in sample	Starchy plants as % of Total Plants
Blombos Cave					
4	I6c CF	Still Bay	58	25	43
5	G7a CFB/CFC	Still Bay	24	0	0
6	G7b CGAB h1	MSA1	77	33	43
7	I6c CGAC	MSA1	14	6*	43
8	G7b CGAC	MSA1	76	31*	41
9	H7a CGAC	MSA1	26	9*	35
10	F7b CFA	Still Bay	29	2	7
* = 50% of sample screened					

7.3.4 Summary of Blombos Results

The densities of starchy plants throughout the hearths at Blombos, with the one exception, attest to plant foods being a recurrent part of the hunter-gatherer diet over the fifteen thousand year sequence of the hearths sampled.

Fragments of parenchyma that appear to have been pulverised prior to heating were found in two hearths CGAB h1 (81 kya) and G7b CGAC (85 kya), both within the MSA II phase. This evidence offers the earliest evidence of multi-step processing yet known. Further, in the latter hearth, there was a significant density of very small legumes, indicating that roots and tubers may not have been the only sources of starch utilised.

7.4 Summary of Results

This chapter has shown, first, the results of the micro-context analysis that supports the hearth features of Klasies River. The analysis highlights that each hearth at Klasies River contained multiple burning events, which, in the light of subsequent broader sampling across the site, appears to be unusual. Most hearths seem to be single-use, making the hearths sampled exceptional. The new sampling technique devised for Klasies River that took oriented block samples, meant that it

was possible to know that the fragments of parenchyma came from the ash layers, not from the carbonised debris layers on which the hearth was set.

Second, the micro-contextual detail from Klasies River contrasts with that of Blombos Cave, where the samples were taken before this innovation. The initial analyses of micromorphology thin sections from Blombos were inconclusive and further research is required (Haaland, 2018, Pers. Comm). Blombos Cave is a very small area, so it is possible that hearths, particularly in this central south section near the cave mouth, would have been trampled. There were also several burrows, probably from rock hyrax, that would cause mixing in the Blombos south section.

Despite the preservation conditions and the challenges of recovering plant remains from both sites, charred parenchyma and starchy plant tissue were recovered from all but one of the samples analysed. The route of these fragments into the context could be: (a) tubers introduced as part of bedding as with sedge grasses (Cyperaceae), which is often used as bedding (Wadley *et al*., 2011); (b) they were brought in as fuel; (c) they were brought in as food.

It is assumed that because these were cave sites, plants with roots and tubers were not growing within the cave and the presence of these remains in a hearth was anthropogenic. Given the hearth context, it seems unlikely that bedding would be burned in the hearth; the MSA example in South Africa at Sibudu Cave shows bedding burned *in situ* (Goldberg *et al*., 2009; Wadley *et al*., 2011). Some of the fragments indicated they had been burned from fresh because of the deformation to the vesicular matrix in the rhizomes; this would appear to rule out the use of roots and tubers as fuel. There is also no ethnographic evidence for the practice of hunter-gatherers using geophytes as fuel. It is, therefore, inferred that the primary reason for the presence of these starchy plant remains in these small hearths, is that they were being cooked as food.

The hunter-gatherers at these sites exploited roots and tubers, aquatic and semi-plants and legumes. The appearance of disrupted parenchyma, with cell walls that are folded or collapsed inwards, rather than crushed or broken caused by mechanical damage post heating or the heating process itself, would indicate

processing prior to burning. Comparison with experimental pounding of tubers, would suggest that some plant remains were pounded prior to being cooked. This potential early processing technique could be a mechanism for detoxifying plant foods and/or creating infant food.

Chapter 8

Discussion

8.1 Introduction

At the beginning of this thesis I discussed the evidence for the biological requirement for a starch diet for *Homo sapiens,* and the hypotheses that starch had a crucial role in providing the energy requirement for human evolution. The strong selective sweep for the human genetic adaptation to starch digestion genes, 300 kya, implies a powerful benefit of a starch diet to *Homo sapiens* in particular at the dawn of our species. A review of archaeobotanical evidence for starch plant consumption, presented in this thesis, indicated little archaeological evidence for before 60 kya.

The research for this thesis has come from five hearths from Blombos Cave spanning MSA II and part of the Still Bay phases (85 - 70 kya) and three hearths from Klasies River Main site: two from the earliest member above bedrock representing the MSA I phase and one from the Howiesons Poort phase (130 and 65 kya). In total these hearths span 65 thousand years of MSA occupation. With one exception, the assemblages from these hearths contained starchy plant tissues that are best explained as direct evidence for cooked starchy foods.

In this research I set out to determine whether the perennial consumption of starch in the human past is a deep or a shallow phenomenon, a deep phenomenon being shown by evidence of consumption of starchy plants from an early human occupation site. Lack of any evidence from such a site would suggest that starchy plant consumption may have been a shallow phenomenon, a feature of the Upper Palaeolithic/Later Stone Age/advent of agriculture.

From these results I have developed four key arguments: first, that perennial consumption of starch was a deep phenomenon from at least 120 kya and second,

far from being a fallback food, early humans cooked roots and tubers as a dietary mainstay; third, that from 85 kya, these hunter-gatherers were pounding, mixing plant foods in a 'recipe' and cooking selected roots and tubers in multi-step processes; and lastly, that based on the persistence of this evidence during warm interglacial and very cold glacial cycles, this subsistence behaviour allowed humans to adapt to changes in environment.

Below, I discuss the key issues that derive from the results of this research. The evidence from the MSA I hearths, showing processing and cooking, and the implications of this early knowledge, suggest starch had a key role as a reliable element of a diet which varied in response to seasonality, climate fluctuations and corresponding changes in vegetation. This evidence of responsive shifts in subsistence strategies suggests dynamic innovation not just in technologies but arguably in behaviour. Finds from Blombos Cave have implied new social behaviour, such as the signalling of social relationships through personal adornment with the use of ochre as body paint and shell bead necklaces. Engraving on bone and ochre and ochre designs on stone also flag a form of signalling. However, these humans also appear to possess a plasticity in behaviour that defines the success of *Homo sapiens*: the ability to adapt successfully to any environment in regions across the planet.

This chapter will start by considering the importance of the hearths themselves. As a context, these have been central to this thesis but they also contain, and could contain more, information on patterns of consumption. I will then draw out the arguments from the botanical analysis in the context of these four arguments, under the heading of Processing and Cooking, and consider the implications of these findings in a broader context. This chapter finishes with a discussion on potential further research based both on the method used in this research as well as the findings.

8.2 Hearths

The micromorphological data were key in the identification of intact hearths at Klasies River. So whilst three hearths may not be a large number for such a large site, these were the only intact hearths visible in section and available for sampling at the time of the fieldwork. The understanding of the micro-context was also invaluable for understanding the contents of the hearths and the stratigraphic relationship between the debris layers and the multiple burning events within the ash layers. By contrast, the hearth data from Blombos were by no means so clear. Although the hearths appeared clear in section, two samples, Sample 4 (I6c CF) and Sample 5 (G7a CFB/CFC), both from the Still Bay phase 74-70 kya, were not intact hearths and may simply have been debris layers with hearth contents distributed across them. Sample 4 contained parenchymous fragments but sample 5 had none. The Blombos off-hearth sample contained only two fragments, suggesting that the background sediment was not rich with charred plant remains. More research is needed to identify intact hearths and the general nature of the hearths at Blombos, *i.e.* are they all trampled with distributed remains or is there evidence of hearth maintenance? Further botanical analysis would be needed then to establish further patterns in the role of starchy plant foods.

The consistent factor in both sites and throughout the sequences is the small nature of the cooking hearths. During the field season at Klasies River (see Chapter 6), the author observed two types of hearth: (a) big roasting pits where elements of mega-fauna such as giant buffalo and elephant were being cooked and possibly had been collectively hunted and; (b) many small ~30 cm radius hearths of the kind sampled for this research. These different hearth types had been previously noted (Deacon, 1995; Singer and Wymer, 1982).

The small ashy hearths from which the samples were taken for this research were multiple burning events, with days, a season or even a couple of years between burning events (Mentzer, 2016, Pers. Comm.). These hearths were used to cook 'small food', but not the big mega-fauna or even large pieces of meat. The fuel gathered was just sufficient and burned relatively quickly in highly oxygenating conditions, with the fuel being possibly turned in from the edges to ensure all was

burned and the fuel used efficiently. The subsequent discovery and analysis of more than 55 single-use hearths support the nature of these burning events. They fulfilled a particular function: perhaps the cooking hobs of the MSA, this was the way that children and adults were fed regular meals. These hearths do not appear to be the kind of fires to sit and tell stories around. They were set on an unprepared surface containing charred and uncharred vertebrate remains and shellfish and were surrounded by lithics/lithic debitage.

Deacon has suggested that the multiple-use hearths or 'storeyed hearths' are one of the first indications of 'modernity' or complexity (Deacon, 1995: 129). Returning to the same hearth stemmed from a sense of spatial organisation. Further, he made the ethnographic comparison with modern San hunter-gatherers, where domestic hearths are the "… domain of women, with reproductive rights and social obligations of child-rearing" (Deacon, 1995). Ethnographic evidence from among the Khoe Khoe and Nharo Khoisan indicates that while meat is shared throughout the band, only the women control the domestic hearths and, importantly, the gathering and distribution of plant food (Barnard, 1992). And the Khoisan are not alone. Across Africa, Southeast Asia, North and South America and Australia, the women of modern hunter-gatherers are responsible for the sharing of foraged food (Barnard, 1992; Bliege Bird and Bird, 2008; Estioko-Griffin and Griffin, 1981; Gould, 1986; Hamilton, 1975; Hayden, 1981; Hill, 1988; Lee, 1979; Watanabe, 1968). Despite the ethnographic evidence, it is not possible to know definitively whether this was the situation for the people using these hearths, but it does appear a viable hypothesis.

I would argue that the hearths themselves, rather than representing the start of modern behaviour as suggested by Deacon, in fact reflect a continuity of behaviour (Deacon, 1995). The hearth from which sample 4 was taken was just above bedrock, representing some of the first human activity at the site. That these small hearths persist in nature and morphology throughout the sequence of occupations at the Klasies main site suggests this was a knowledge these people brought with them when they first encountered the site and this knowledge had been transmitted to subsequent visitors over thousands of years.

As noted in the previous chapter it is not possible to know which hearths are coeval without dating, so we do not know how many people or families occupied this site at any one time, especially at Klasies River. Woodburn highlights the fluidity of camp membership at any one time among the Hadza; it varied from one to fifty whilst they were still a nomadic hunter-gatherer group (Woodburn, 1968). Without these data, it is impossible to draw such inferences about social organisation. The distance between coeval hearths may also have some significance but until these aspects of excavation are recorded and published, it will be impossible to infer social patterns from spatial relationships.

Klasies River had the potential for a larger band to organise co-operative hunting strategies on a larger scale during MSA 1 and MSA II. The Howiesons Poort phase is found in the larger Cave 2 and Cave 1A, the latter being effectively a rockshelter and much smaller. Defined by blades and bow and arrow technologies, it may be that an ability to kill at a distance with arrows might have changed the profile of prey during the Howiesons Poort phase (Lombard and Pargeter, 2008). There were no roasting pits in Cave 1A large grindstones recovered from the Howiesons Poort sequences in this cave, indicate possible charring on one end or one side. Further research is needed on these grindstones but they possibly herald different, indirect heating, cooking methods. Stone-lined hearths are known from the Upper Palaeolithic/Later Stone Age (Thoms, 2009).
The purpose of these grindstones has yet to be established, and they present further opportunities for research, but the charring and rubification on the sides of the grindstones offer the possibility of side stones for a more diffused heat.

Similarly at Blombos, small hearths with whole tortoise carapaces were not unusual (Figure 8.1), but this research shows clearly that these hearths cooked small food, including starchy plants.

Figure 8.1: Whole tortoise carapace in a Still Bay hearth, southern section, Blombos Cave. (Image: C. Larbey)

Thompson & Henshilwood maintain that the hunter-gatherers of Blombos could have subsisted on foraged food alone. The availability of tortoises, ostrich eggs, and marine resources could have provided sufficient nutrition on which to live. (Thompson and Henshilwood, 2014: 43). By dating and treating hearths as features, a multi-disciplinary approach, with total station, micromorphology, botanical and zooarchaeological analysis, might in future gain a better understanding of patterns of social behaviour and consumption.

8.3 Processing and Cooking

The nature of the evidence is charred remnants of cooked plant food that falls or is thrown into the fire. By their very nature, most of the roots and tubers would have been consumed, either by fire or by being eaten. A television documentary, featuring Gordon Hillman's travels in Australia with Ray Mears, showed women from the Warlpiri tribe from the Tanami Desert, Western Australia, cooking bush potato (*Ipomoea costata*) and wild yams (*Dioscorea* sp.) in the ashes of a fire. Once the potatoes were cooked and cooled, they peeled the outer skin, which they threw back into the fire and ate the contents (Graham-Brown, 2007a). Such might be the route into the archaeological record for much of the archaeological evidence discovered here. The evidence appears to come mostly from taproots, rhizomes and tubers that would have been in rich supply on a year-round basis around Blombos and Klasies River.

The recovery of two aerenchyma fragments from the off-hearth sample in the Howiesons Poort phases would indicate they were exploiting semi-aquatic species, possibly from Klasies River itself, although sedge grasses and rush species may once have grown around the water springs around the cave. Many of the fragments could be classified as monocots. This is not surprising as 83% of the Cape species are monocots, with 79% of those belonging to the Asparagales order. This balance was noted in the collection of species for the modern parenchyma reference collection. As Iridaceae and Hyacinthaceae families form 60% of the endemic geophyte species in the Cape, these may well have formed a large percentage of the starchy plants sources. The vascular structure of Fragment 6, sample 5 (Figure 7.31) from the MSA I phase at Klasies River suggests it may come from one of the families of the Liliales order, endemic to this region (Proches *et al*., 2006). As both sites are located within Fynbos and Strandveld areas, there would have been year-round availability of starchy plants, with greater availability in the spring/autumn seasons. These seasonal adaptations to different plant availability, in different locations is something Martin Jones has called 'ecological intelligence' (Jones, 2009: 173). The Cape Mediterranean-type climate can experience searing summer heat and aridity and cold winter heavy rains, sometimes with snow (Marean *et al*., 2014). The seasonal adaptations would have equipped these people well for subsequent climate fluctuations that oscillated between warm and cold.

The parenchyma evidence from eleven out of twelve samples, over two sites, with the Klasies River samples from intact hearths, would imply that perennial consumption of cooked starchy plants was already in place by 120,000 years ago. Further, the fact that the parenchyma was found in hearths distributed through sequences up to 65,000 years apart suggests, that starchy plants are not fall back foods but a dietary mainstay, and also represent a behaviour that persisted through periods of significant climate change.

The evidence presented from across the sequence at Klasies River and more starkly from Blombos is strikingly consistent, with hearths 4-5 thousand years apart indicating similar cooking processes despite coming from warm and cold climatic conditions (Figure 8.2) (Roberts *et al*., 2016). These climate oscillations

may have had consequent vegetational changes in the immediate vicinity of the caves but, as the Cape Floristic Region is defined by the fact that there have been few plant extinctions, any dramatic changes in the vegetation seem unlikely. Cooking of roots and tubers persisted through this period of climate fluctuation, which would suggest that roots and tubers were not fallback foods. There may have been seasons or periods when preferred roots and tubers were scarce but it is possible that cooking would make the least preferred but continuously available roots and tubers both digestible and palatable. Cooking may also have extended the range of plants used and thereby intensified the productivity of the landscape (Marlowe and Berbesque, 2009; Marshall and Wrangham, 2007). Across these periods of climate fluctuations, the cooking of roots and tubers would have been a technology that allowed exploitation of a sustainable and reliable food source and adaptation of foraging strategies accordingly.

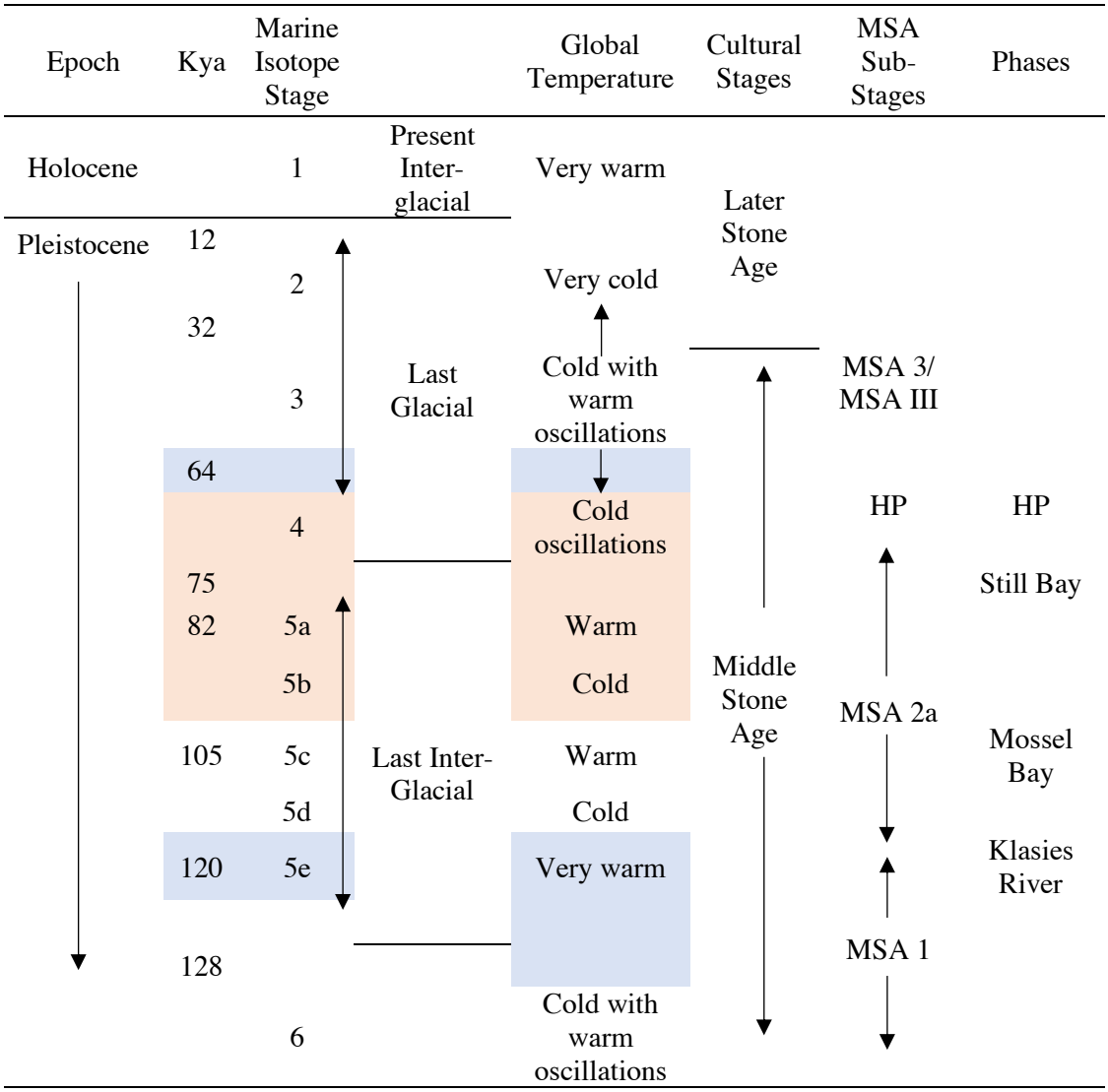


Figure 8.2: MSA sequence for southern Africa with equivalent marine oxygen isotope stages. Blue background = phases from which Klasies River samples were taken - 130 kya (MIS 5e) and 65 kya (MIS 4) and Orange background = phases from which Blombos samples were taken – 85 kya (MIS 5b), 81 kya (MIS 5a), 77 kya, 75 kya and 70 kya (MIS 4). (Image adapted from Henshilwood *et al*. 2001: 426)

In these same hearths, I also identified pounding or pulverising of selected plant remains, prior to heating, from two hearths at Blombos, within 4-5 thousand years (81 and 85 kya).

Pounding has also been associated with denaturing toxins in roots and tubers (Carmody and Wrangham, 2009). This is in part the case. There are two groups of toxic compounds associated with roots and tubers. The first are the calcium oxalate crystals, detailed in Chapter 7, that take the form of raphide, rhomboid or the more rare druse crystals (Figures 8.3A, 8.3B and 8.3C). The second are the toxic secondary compounds found in many plants such as alkaloids, saponins and

glycosides and stored in secretory cavities (Figure 8.3D). Throughout both assemblages, raphide, rhomboid and occasionally druse calcium oxalate crystals were common (Figure 8.3) although secretory cavities were rare in the archaeological assemblage (Figure 8.3D).

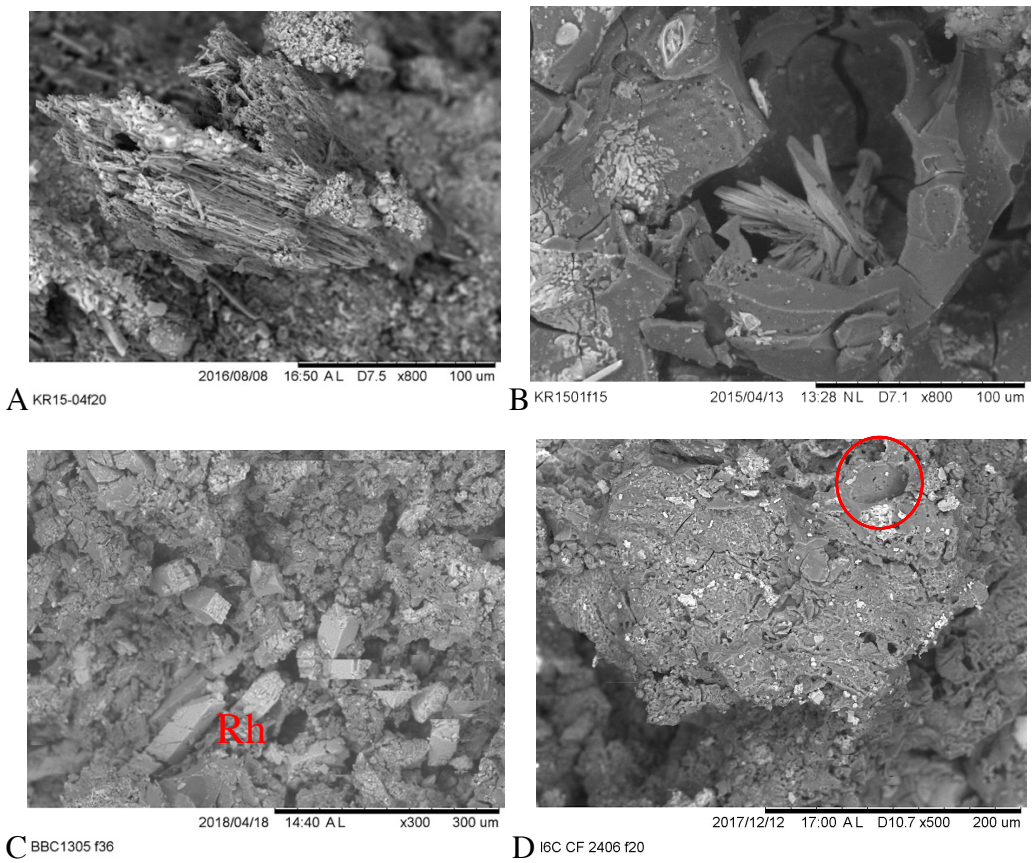


Figure 8.3: Calcium oxalate crystals and secretory cavity. A: raphide crystals (fragment 20, sample 4 MSA I Klasies River); B: druse crystal (fragment 15, sample 1 Howiesons Poort, Klasies River); C: rhomboid crystals (fragment 36 sample 4, I6 CF Blombos); D: Secretory cavity (fragment 20, sample 4 I6 CF Blombos). (Micrographs: C. Larbey)

Cooking alone does not remove toxins from plant foods, although it may remove pathogens. Most toxins are stable at normal cooking temperatures of ≥100 °C. Heating de-activates the enzymes that would help to breakdown stable allelochemicals such as cyanogenic glucosides (Johns and Kubo, 1988). Pounding is a comminution process that helps to release the enzymes that break down toxins, although in some instances further leaching, roasting or boiling may be needed (Johns and Kubo, 1988; Nic Eoin, 2016). Archaeological evidence of this can be seen as early as 50 kya from the Niah Caves, Borneo (Barker *et al.*, 2007). In the

case of calcium oxalate crystals, cooking alone does not break these down and a combination of pounding and cooking may be needed (Stahl, 1989).

Raphide crystals were common in both the archaeological and modern parenchyma reference assemblages. The bulb of *Trachyandra ciliata* (Common Cape Spinach) was processed for the modern reference collection, although ethnographic reports suggest only the leaves and stems are used for soup (Manning, 2008). The bulb contained a high density of raphides in bundles that are toxic (Figure 8.4), which may explain why this part of the plant is not used.

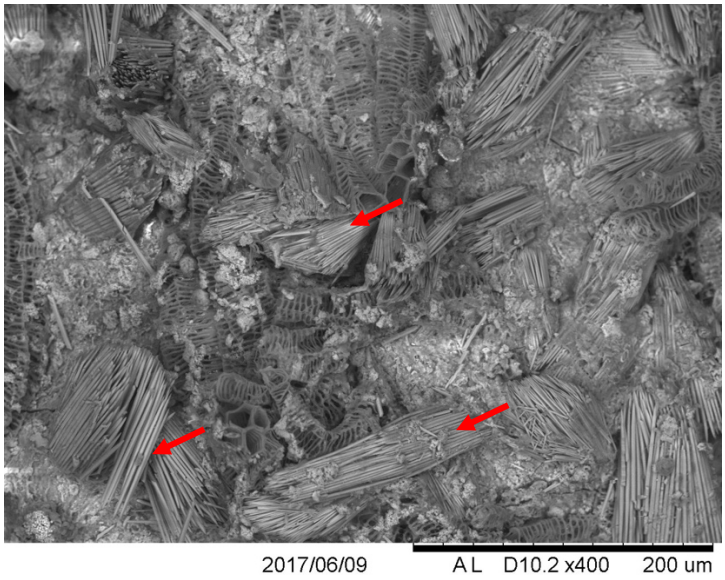


Figure 8.4: *Trachyandra ciliata* bulb with a high density of raphide bundles. From the modern parenchyma reference collection, Klasies River collected by author. (Micrograph: C. Larbey)

These toxins are both a by-product of the plant's growth metabolism and part of its defence against herbivory (Franceschi, 2001; Franceschi and Horner, 1980; Stamp, 2003). However, they may explain the pounding and cooking of the fragments from the two hearths at Blombos.

Weaning infants may provide another explanation for pounding, although the evidence of this processing was not seen at Klasies River. The ethnographic evidence for feeding infants on foraged foods that are either pre-chewed (Han *et al.*, 2016) or processed by pounding or grinding, is widespread (Barnard, 1992; Crittenden *et al.*, 2013; Hames, 1984; Hill and Hurtado, 2009; Lee, 1978). As

discussed above, Hillman raised the question of identifying infant faeces with them having been fed on acorn mush from Wadi Kubbaniya (Hillman, 1989).

The technique of pounding is used by chimpanzees (Figure 8.5) both to open hard-shelled nuts but also to pound palm pith to a paste (Haslam, 2016). There is also evidence to suggest that pounding was a process used by Lower Palaeolithic *Homo* species (Carmody and Wrangham, 2009). It seems possible that the technique of pounding, along with the control of fire and the ability to cook was learned by species within the genus *Homo*. And, therefore, likely that pounding as a form of plant processing was probably known before *Homo sapiens* emerged. However, human multi-step plant processing by pounding and cooking in a single species, as far as the author is aware, has not been identified at this early stage before.

Figure 8.5: Chimpanzee using stone hammer tools to open nuts. (Image: ©Susan Cavalo and used with her kind permission)

Evidence for processing, mixing and cooking plant foods (Figure 8.6) shows just one example from sample 6, of ruptured seed testa mixed with pulverised parenchyma cells. Seed testa are often found whole, even after passing through the human digestive system (Rowan, 2017) and are often only ruptured after processing (Nic Eoin, 2016). The combination of pulverised parenchyma and ruptured seed testa in a cooked matrix would suggest the mixing of these two plants for food. The reason for this may well be for taste/flavour, where seeds are used as a condiment, and where the pulverised tuber is used as a matrix for picking up and eating seeds. This fragment is one of four fragments that have the appearance of mixed plant foods being processed and cooked together; I infer that

this is an 81,000-year-old ‘recipe’ of plant foods processed and mixed for flavour and taste.

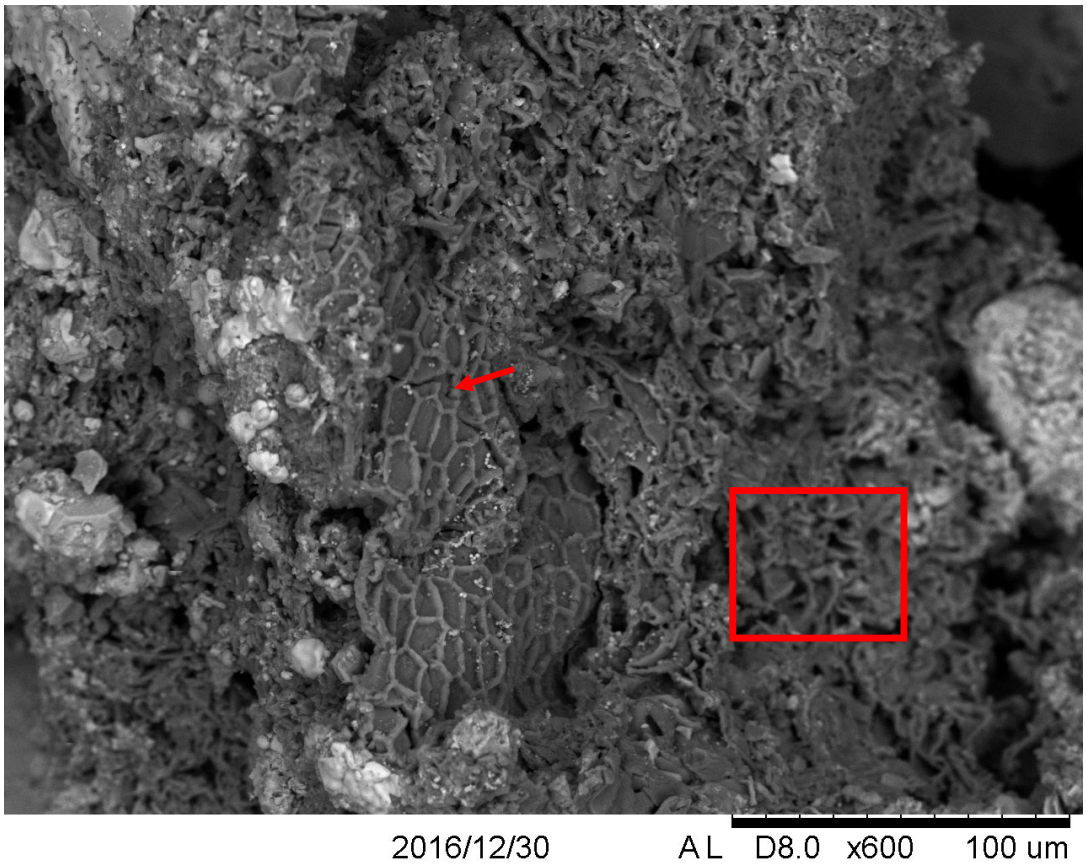


Figure 8.6: Plant food ‘recipe’: mixed, processed and cooked plant food. Ruptured seed testa (red arrow) in a pulverised parenchyma matrix (example in red square) from 81,000-year-old hearth. (Micrograph. C. Larbey)

Hillman and Wollstonecroft (2016) argue that diet choices, nutrition, and processing are strongly linked to ethnic/group identity, and that this identity is constructed less by ‘what’ is eaten but more by ‘how’ it is prepared (Hillman and Wollstonecroft, 2016: 40). This seems a strong argument to apply to only four fragments. However, when placed in the context of persistence through climate change over the Blombos sequence, and the nature of the material culture recovered from Blombos Cave, it seems possible to argue that ‘recipes’ of mixed pounded, mixed and cooked plant foods might also be a subsistence strategy that forms part of a group’s identity.

8.4 Summary of Thesis Results

From the results described in this thesis, I have inferred that the hunter-gatherers of Klasies River and Blombos consumed cooked starchy plant foods during their multiple occupations through the MSA between ~130kya and 70kya. And for Blombos, the small group of people that visited this cave had the knowledge to pound roots or tubers before cooking. This evidence is the first and earliest evidence so far of human cooking, multi-step processing and mixing of starchy plant foods. At these dates, I conclude that human perennial consumption of starch is a deep phenomenon in the past of *Homo sapiens*.

I also suggest that starchy plants were a recurrent dietary element of the MSA hunter-gatherer diet that persisted through seasons, and climate and ecological changes, despite evidence of changes in hunting and other subsistence strategies. This evidence suggests that the regular consumption of cooked starch plants was a dietary mainstay over this long episode.

The very lowest level of Klasies River (~130 kya), in the LBS member just above bedrock, contains an ashy hearth from which parenchyma was recovered. From this it is inferred that these humans came to the cave knowing how and when to find roots and tubers in this area and which of them needed to be cooked. The sequence at Klasies over the intervening 55 thousand years demonstrates human plasticity over cycles of climate change. This is corroborated by other evidence such as the lithic innovations, seen in the Still Bay points and Howiesons Poort segments, which align with changed profiles of foraged and hunted vertebrate remains to provide an overall picture of climate-mediated changes in subsistence strategies. But not everything was impacted by climate. The consistent nature of these cooking hearths suggests the ability to find and process starchy plants foods, despite climate-driven ecological changes. This may be the ultimate skill enabling the dramatic adaptation which underpinned the human plasticity that allowed our species to colonise most biomes of the planet.

The evidence for multi-step processing discovered at Blombos was taken from two samples that, although only around 4-5 thousand years apart, date from a warm

phase and a cold phase in climate sequence within MSA II. As with Klasies River, starchy plant foods appear to be the buffer against the less predictable food sources. However, this multi-step processing is not seen in the later levels and it would appear that either the plant foods that needed this processing disappeared or the knowledge and skill of pounding and cooking moved with different groups, or were forgotten. Although there has been considerable evidence of grindstones, there is no link yet between these and the processing of tubers until the Upper Palaeolithic (Revedin *et al*., 2010) and this evidence comes from grindstones, not from the foodstuff. This discovery presents the earliest direct evidence of tuber processing, predating the evidence from Niah Cave, Borneo, for example, by 30 thousand years. The evidence of the processing, mixing and cooking of plant foods in an 81,000-year-old 'recipe predates and the most recent evidence from Shubayqa 1, Jordan, by 70 thousand years. The evidence from Shubayqa 1 reveals bread-like products that included club-rush tubers (*Bolboschoenus glaucus*) and date to 14,400 years ago (Arranz-Otaegui *et al*., 2018a).

8.5 The Implications of these Findings

Whilst it is not suggested that humans from the Cape migrated directly from Africa to other regions of the world, there are technologies and capabilities identified in this research that could explain human success in colonising different environments across the planet.

8.5.1 Ecological intelligence

The term 'ecological intelligence' was coined by Jones as meaning the ability of our human ancestors to identify edible plants in season and to remember where those plants were in various geographically diverse areas. It also encompassed the ability to distinguish the edible from the toxic and those plants that were edible at certain times of year and not at other times (Jones, 2009: 173). As discussed above, it seems likely that many of the tubers were from monocots. Monocots are often distinguished by softer stems, with less lignin that dicots and often with fleshy underground stems, such as tubers (Jones, 2009b). Monocots also have distinct parallel-veined leaves that may act like flags to signal a potential food

source underground. In general monocot roots and tubers are less likely to be toxic than dicots, although taro and yam contain significant amount of toxins (Jones, 2009b). The ability to distinguish species, such as monocot leaves that signal food in the landscape, was integral to the development of an ecological intelligence that allowed foragers to navigate new as well as familiar landscapes (Jones, 2009b).

Many archaeological sites across the world where evidence of roots and tubers have been found recover similar species. These species have formed the backbone of the modern parenchyma reference collection, gathered around Blombos and Klasies River, such as *Cyperus esculenta*, *Watsonia* sp., *Hyposis* sp., and *Oxalis* sp. The repeated occurrence of Cyperaceae in archaeological assemblages across the world affirms the importance and productivity of water and of semi-aquatic species. Walsh has noted that plant food resources, not animal habits, especially water vegetation, determined gathering and mobility strategies of the Australian Martujarra (Walsh, 1987).

The knowledge and ability to deal with plants toxins reduce the risk of moving into new environments, particularly north into colder, seasonal environments where plant defence mechanisms increase the levels of plant toxicity compared to those in warmer environments, where the period for reproduction is not contained in one short season.

Hunter-gatherers moving into temperate and cooler latitudes would have encountered not just seasons when the total biomass reduced but where plants with a short season in which to reproduce have evolved barriers against being eaten by animals. This defence mechanism may involve spines, chemicals that deliver a sting, toxic secondary metabolites, calcium oxalate or calcium carbonate crystals and other barriers to digestion (Freeland and Janzen, 1974; Stamp, 2003). Tannins from plants such as oak are an example of the latter, where the amount of tannins consumed by the herbivore disrupt the digestion of the food, slowing animal growth if it continues to consume these plants (Herms and Mattson, 1992; Stamp, 2003). In moving north, and certainly into the Americas, migrating early humans would have encountered a significantly more toxic plantscape. The ecological intelligence suggested by Jones, and supported by the evidence in this research,

would have been integral to the human ability to survive and traverse these landscapes (Jones, 2009b).

8.5.2 Technologies

I have said above that I consider cooking hearths and the ability to cook and process starchy plant foods to be the ultimate tools for adapting to different environments. Some of this is to do with the control of fire, as is clear at Klasies River, with small, quick, functional, oxygenating fires that burn to completion leaving only ash layers behind compared to the large, long, slow, reducing conditions in which they cooked the mega-fauna excavated at Klasies River Witness Baulk. There is a need to investigate the role of the large stones found in the Howiesons Poort phase at Klasies River to assess the likelihood of these possibly representing a different kind of cooking/heating method, as well as possibly a grinding surface. If so, cooking stones or hot rocks, known in America from 10 kya (Thoms, 2009), would represent another innovation in cooking technology from a far deeper context than previously understood.

The innovations in lithic and bone technologies from these two sites have been discussed extensively and attributed to climate change (Roberts *et al*., 2016). However, I would argue that plant foraging, processing and cooking strategies that account for stable subsistence through seasons and climate change may have provided early humans with the flexibility to migrate to new environments. In this, the only 'technologies' required would be digging sticks and the knowledge of how to create and control fire. In all but Arctic environments, roots and tubers would have been/are available in most regions of the world and monocots would have been recognisable in the landscape. It has been suggested recently that humans are generalist specialists in their diets because they have been able to colonise niches by adapting their generalist diet to a niche, in some cases extreme, environment (Roberts and Stewart, 2018). I consider this to be partly true. This thesis offers insight into the early human ability to maintain a starch diet, through cooking and processing roots and tubers unvaryingly through cycles of warm and cold. Our ability to apply that knowledge and ability to new environments, to identify familiar plant species and process potentially toxic plants to exploit fully a

new landscape, exhibits our uniquely human plasticity at its most fundamental level.

8.5.3 Roots and Tubers as Fallback Foods

The recovery of parenchymous remains from Blombos Cave and Klasies River opens the discussion about the importance of carbohydrates in the human diet and raises new questions challenging the theory that roots and tubers provided a fallback option in the MSA diet.

The climate changes in Africa during the late Miocene and into the Pliocene resulted in a reduction of forested areas in favour of a mosaic of savanna, marshland and forest. The consumption of roots and tubers by early hominins of the late Miocene has been proposed as a consequent adaptive shift to the new seasonality of food availability and periods when higher ranked food sources were scarce (Dominy, 2012; Dominy *et al*., 2008; Laden and Wrangham, 2005) and to a new mosaic of vegetation biomes.

Whilst certain roots and tubers may have been used as fallback foods, it is difficult to identify fallback foods without understanding both the full availability of other food sources and how they were exploited. How otherwise would it be possible to differentiate between fallback foods and dietary mainstays? (Sayers and Lovejoy, 2014).

In research conducted on the Cape coast of South Africa, archaeological evidence was compared with modern hunter-gatherer evidence for inter-tidal marine foraging, which highlighted that harvesting of shellfish was only possible for ten days per month and 2-3 hours each day. The lowest returns were recorded in the winter and spring when strong winds and high seas prevented harvesting (De Vynck *et al*., 2016a). A similar exercise with roots and tubers resulted in a successful harvest, sufficient to sustain a carbohydrate diet throughout the year (De Vynck *et al*., 2016b; De Vynck *et al*., 2016c). Such evidence suggests that there are periods when hunter-gatherers would have had to place greater reliance

on roots and tubers that were, in any case, a regular part of the diet (Singels *et al*., 2016).

The archaeological evidence from my research indicates continued root and tuber processing and cooking through warm and cold climate cycles, indicating that climate change is not a big driver in their selection as dietary constituents. When combined with evidence of early human duplication of starch digestions genes, it is difficult to hypothesise that the consumption of starch roots and tubers as fallback foods might be responsible for one of the strongest selective sweeps seen in the human genome.

8.6 Further Research

Key among the things achieved by this research, I would suggest, is the adaptation to methods and understanding of context that make it possible to recover plant remains and to reconstruct diet from deep time contexts. These methods and discoveries open significant areas of research. The following represent a small proportion:

Firstly, there are many more questions to ask about the starchy plant diet of early humans. Simply more of this kind of research is needed if we are to understand the origins of one of the main energy-providing elements of the human diet. This is the case not just along the Cape coast of South Africa but across Africa in sites such as Jebel Irhoud, the site of the earliest fossils of *Homo sapiens* (Hublin *et al*., 2017). How far back does this knowledge and skill go? Hardy *et al*. proposed that only starches could have provided the energy required by *Homo erectus* for the significant morphological changes made by that species (Hardy *et al*., 2015). Is there archaeological evidence for this hypothesis? Are there *Homo erectus* sites where these plant cooking and processing behaviours may be recovered and observed? With increasing numbers of *Homo erectus* sites being uncovered in China, this may be a question for that research (Zhu *et al*., 2018).

Further research into the diet of Neanderthals and Denisovans would help to understand how the early human starch diet differed from these archaic species and how and if that related to climate adaptations.

The knowledge of multi-step processing (85 kya) and plant food mixing (81 kya) at Blombos, begs the question how far back does this knowledge and ability go? A better understanding is needed of the effect of processing techniques on charred plant remains, the effect on plant matrices of processes such as fermentation, and an awareness during excavation that some tools that may look like hammerstones, may in fact be plant pounding or grinding stones.

If humans have the ecological intelligence to exploit plant communities in new environments and the ability to detoxify where necessary, can we see evidence of this as humans move out of the Old World into the New World? This last question is a key question for the Americas that has some of the world's most toxic plant families (Turner, 1997). Ugent suggests that from 13 kya hunter-gatherers in Chile are already cultivating wild potatoes (*Solanum maglia*) that would have been highly toxic (Ugent *et al*., 1987).

If the myth that 'plants remains are not preserved in deep time contexts' is taken away, then there are many research opportunities for archaeobotany.

8.7 Conclusion

In the Introduction the temporal concepts of "deep" and "shallow" were discussed in terms of whether the human starch diet was a dietary trend of the agricultural age, contained within the last twelve thousand years, or whether it was an important feature of the Pleistocene hunter-gatherer diet, therefore placing more emphasis on foraging.

The evidence from the various hearths in the cave sequences from Blombos and Klasies River covers fifty-five thousand years, and suggests that these starchy plant foods were a persistent part of the diet of these early, not yet fully

anatomically modern human hunter-gatherers. The further evidence of multi-step food processing, including the earliest evidence of human use of pounding plant and plant food mixing remains, up to 85kya, 70,000 years earlier than the most recent other evidence is significant, but that this evidence comes from hearths from two different climate cycles, infers a persistence in behaviour and continuity in diet that is only matched by the evidence of the exploitation of marine resources during the MSA. It is inferred from this evidence, therefore, that plant starch consumption is indeed a deep phenomenon in the human past, and we are only beginning to understand its importance in the evolution of humans.

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